U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-291 369

Pollution Control Guidelines for Coal Refuse Piles and Slurry Ponds

W. A. Wahler and Associates, Palo Alto, CA

Prepared for

Industrial Environmental Research Lab -Cincinnati, OH

Nov 78

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/7-78-222
November 1978

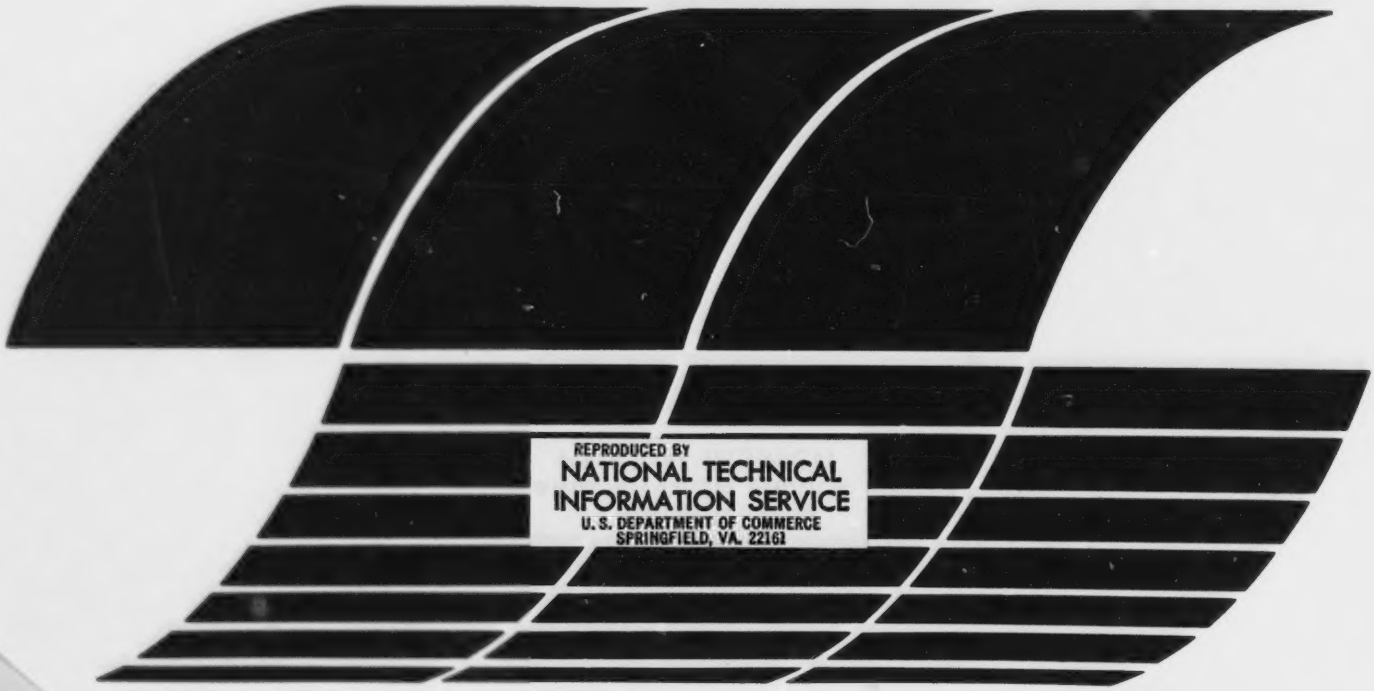
PB 291369

Research and Development

JAN [illegible]

Pollution Control Guidelines for Coal Refuse Piles and Slurry Ponds

Interagency Energy/Environment R&D Program Report



REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/7-78-222

2.

3. RECIPIENT'S ACCESSION NO.
PB291369

4. TITLE AND SUBTITLE
Pollution Control Guidelines for Coal Refuse Piles and Slurry Ponds

5. REPORT DATE
November 1978 issuing date

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
W. A. Wahler and Associates

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
W. A Wahler and Associates
1023 Corporation Way
Palo Alto, California 94303

10. PROGRAM ELEMENT NO.
EHE623 EHB-526

11. CONTRACT/GRANT NO.
68-03-2344 & 68-03-2431

12. SPONSORING AGENCY NAME AND ADDRESS
Industrial Environmental Research Lab. - Cinn, OH
Office of Research & Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final 12/75 - 7/77

14. SPONSORING AGENCY CODE
EPA/600/12

15. SUPPLEMENTARY NOTES
Combined Final Report for Contracts 68-03-2344 and 68-03-2431

16. ABSTRACT

A large percentage of the eastern coal mined today is washed and processed to remove impurities and increase quality. The wastes from the preparation process pose a serious disposal problem. The study investigated acid and heavy metal ion concentrations in water passing through refuse piles, suspended solids in waters from refuse areas and slurry ponds, noxious gases from oxidation and fires in refuse piles, and airborne particulates from dry exposed refuse surfaces.

The report compiles information on construction practices applicable to pollution control from coal refuse disposal sites. Water pollution from old, acid-producing refuse piles and erosion of steep refuse banks was found to be a serious concern, as was pollution caused by suspended solids from slurry ponds. Present placement procedures combined with removal of a higher percentage of coal from refuse have restricted the burning bank problems to older disposal sites. With proper planning, coal refuse disposal sites can be put to useful purposes and become an asset rather than a liability.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
coal mines waste disposal dust control air pollution coal dust ponds	pollution control acid mine drainage slurry ponds refuse piles Eastern United States	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 228
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE PC A11 MF A01

☆ U.S. GOVERNMENT PRINTING OFFICE: 1979-657-060/1542

EPA-600/7-78-222
November 1978

POLLUTION CONTROL GUIDELINES FOR COAL REFUSE PILES AND SLURRY PONDS

by

W. A. Wahler and Associates
Palo Alto, California 94303

Contract Nos. 68-03-2344 and 68-03-2431

Project Officer

Edward R. Bates
Extraction Technology Branch
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

Reported here are the results of a study to investigate acid and heavy metal ion concentrations in water passing through refuse piles, suspended solids in waters from refuse areas and slurry ponds, noxious gases from oxidation and fires in refuse piles, and airborne particulates from dry, exposed refuse surfaces. The report compiles information on construction practices applicable to pollution control from local refuse disposal sites and concludes that with proper planning coal refuse disposal sites can be put to useful purposes and become an asset rather than a liability. For further information contact the Extraction Technology Branch of the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

The objective of this study was to develop pollution control guidelines for construction, operation, and reclamation of coal refuse disposal piles and slurry ponds. Eight active refuse pile sites and six slurry pond sites in the eastern coal-mining region, selected as representative of the best technology and operating procedures now in use for reducing water and air pollution hazards, were evaluated. Detailed air and water quality sampling programs were carried out in conjunction with in-depth studies of disposal facility construction, operation, and reclamation methods.

It was concluded that environmentally acceptable refuse piles and slurry ponds can be developed and operated using current technology (most of which is available now in the mining and construction industries). For refuse piles, proper layering and compaction techniques, drainage control (particularly of acid drainage), diversion of surface and ground waters around refuse piles, and ongoing reclamation of finished surfaces by covering them with selected materials and promoting vegetative growth will combine to reduce both air and water pollution. For slurry ponds, acid water drainage through dams or abutments, as well as suspended solids in waters from the ponds, constitute the major pollution control concerns. These problems can be minimized by: (1) properly discharging slurry into ponds and maximizing slurry travel distance through the ponds to obtain maximum settling of suspended solids; (2) proper design of slurry retention dams; (3) avoiding large flowthroughs of runoff from upstream drainage areas; (4) returning clarified pond waters to preparation plants for reuse; (5) isolating contaminated seepage waters from ground and surface waters; and (6) collecting seepage below retention dams, treating it (if necessary), and releasing it or pumping it back to the slurry ponds.

This report was submitted in fulfillment of Contracts 68-03-2344 and 68-03-2431 by W. W. Wahler & Associates under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period December 3, 1975 to December 16, 1977, and work was completed as of June 30, 1978.

CONTENTS

Foreword iii
Abstract iv
Figures vii
Tables. viii
Abbreviations ix
Acknowledgments x

Section

1 Introduction 1
  Statement of the Problem 1
  Purpose of the Study 2
  Scope of Work 2
  Method of Approach 3
  Report Organization 5
2 Summary of Findings and Pollution Control Guidelines 7
  Findings 7
  General Conclusions 10
  Summary of Guidelines. 11
  Suggestions for Future Research 14
3 Coal Refuse Properties 16
  Pollution Mechanisms 16
  Properties of Coarse Refuse 20
  Properties of Fine Refuse 38
4 Preparation Plant Procedures 44
  Refuse Recovery Circuits 44
  Process Quantities 45
  Material Sizing. 45
  Summary of Principal Guidelines 47
5 Site Selection 48
  Environmental Considerations 48
  Coal Refuse Deposit Classification System 50
  Pollution Control 53
  Summary of Principal Guidelines 56
6 Conveyance Systems 57
  Coarse Refuse Conveyance 57
  Slurry Transport Systems 58
  Summary of Principal Guidelines 59
7 Guidelines for Refuse Pile Construction and Operation 60
  Site Preparation 60
  Site Development 64
  Site Operation 69
  Summary of Principal Guidelines 78

Page

8 Guidelines for Slurry Pond Construction and Operation 80
- Slurry Pond Water Circuits 80
- Pond Operation 84
- Temporary Slurry Ponds 87
- Slurry Retention Dams and Dikes 87
- Pond Inspection and Maintenance 91
- Summary of Principal Guidelines 91

9 Guidelines for Reclamation and Abandonment 93
- Refuse Piles 93
- Slurry Ponds 96

10 Alternative Disposal and Pollution Control Methods 98
- Burial of Refuse in Surface Mine Spoil Piles 98
- Underground Disposal 99
- Use of Refuse as Construction Material 99
- Dry Disposal of Fine Coal Refuse 100

References 102

Appendix A Results of Site Investigations and Sampling Programs . . . 104

Appendix B Field and Laboratory Tests Used to Determine Refuse Properties 194

Glossary of Geotechnical Terms 205

Glossary of Coal Preparation Terms 211

FIGURES

Number		Page
1	Gradation Summary, Coarse Coal Refuse	22
2	Gradation Summary, Fresh Coarse Coal Refuse	23
3	Atterberg Limits, Coarse Coal Refuse	25
4	In-Place Dry Density, Coarse Coal Refuse	28
5	Natural Moisture Content, Coarse Coal Refuse	29
6	Effects of Grain Size on Permeability of Coarse Materials	31
7	Effects of Fines on Permeability of Coarse Materials	32
8	Gradation Summary, Fine Coal Refuse	39
9	Natural Moisture Content, Fine Coal Refuse	41
10	In-Place Dry Density, Fine Coal Refuse	42
11	Simple Refuse Pile Forms	51
12	Simple Slurry Pond Forms	51
13	Example of Subdrain	62
14	Site Development: Valley-Fill Refuse Pile	65
15	Site Development: Side-Hill Refuse Pile	66
16	Cell Development Plan for Waste Heap	67
17	Alternative Development Plan for Waste Heap	68
18	Improper Refuse Placement by Truck Dumping	71
19	Improper Refuse Placement by Aerial Tramcar Dumping	71
20	Slurry Pond with Fine Refuse Delta	82
21	Flood-Water Storage for Prevention of Downstream Pollution	83
22	Upstream Slurry Discharge System	83
23	Methods for Raising Slurry Pond Embankments	89
24	Zoned Dam Section	90

TABLES

Number		Page
1	Average Changes in Water Pollutant Concentrations between Water Inlet and Outlet Points	9
2	Averaged Air Quality Data for All Sites Sampled	11
3	Effects of Weathering on Coarse Refuse	27
4	Compaction Characteristics of Coarse Coal Refuse	30
5	Selected Chemical Characteristics of Underground Mine Refuse Samples	34
6	Analyses of Effluents from Refuse from Mines in Five Eastern U.S. States	35
7	Coal Refuse Production at Study Site Plants	46

ABBREVIATIONS

cm	centimeter	ℓ	liter(s)
cu yd	cubic yards	lb	pound(s)
ft	foot/feet	m	meter(s)
ft^2	square feet	m^2	square meter(s)
ft^3	cubic feet	m^3	cubic meter(s)
$ft-lb/ft^2$	foot-pounds per square foot	mg	milligram(s)
gal	gallon(s)	mg/ℓ	milligram(s) per liter
gpm	gallons per minute	mgd	million gallons per day
gm	gram(s)	Mt	metric tons
ha	hectare	Mt/d	metric tons per day
in.	inch(es)	Pa	Pascal(s)
kg	kilogram(s)	tpd	ton(s) per day
km	kilometer(s)	yr	year

ACKNOWLEDGMENTS

Many individuals in government agencies (particularly in the U.S. Bureau of Mines and the Mine Safety and Health Administration) offered valuable advice and assistance in the site selection phase of this study, as did members of the staff of the American Mining Congress. During final site selection, officials and operating personnel of many disposal sites materially assisted the study team with the site examinations. The cooperation of all these people is gratefully acknowledged.

The participation and wholehearted cooperation of the mine company managements and the operating personnel of the nine selected sites was invaluable to the project team in carrying out the field work. Despite extremely adverse winter weather conditions, and despite their own busy schedules, the personnel at all nine sites were always ready to assist the field crews in completing each site visit with a minimum of difficulties. This generous response was in the great tradition of the mining industry to freely share operating experience and successful technological innovations. This study is truly the result of outstanding cooperation among government research and regulatory groups, industry management, and site operating staffs.

The subcontractor for the water quality field and laboratory testing was Environmental Control and Technology Corporation of Ann Arbor, Michigan. USC Incorporated, of Pittsburgh, Pennsylvania, carried out the air quality field sampling and laboratory testing programs.

SECTION 1

INTRODUCTION

STATEMENT OF THE PROBLEM

With renewed interest in and demand for coal as a source of energy has come a growing emphasis on pollution control in coal mining and utilization activities. Much of the coal mined in the eastern United States today is washed and processed to remove impurities and enhance quality, and the refuse created during processing must be disposed of in an environmentally acceptable manner. Coarse refuse, composed of chunks of soft shale or sandstone rocks that range in size from sand to coarse gravel or cobbles, is generally disposed of in dry landfills (called "refuse piles"). Fine refuse, a silt-sized material, is usually transported from the processing plant in slurry form and disposed of in settling ("slurry") ponds.

Four general types of pollutants--two affecting water quality and two affecting air quality--are created by coal refuse disposal operations:

- Acids and heavy metals -- these go into solution and create "acid drainage" problems when waters come into contact with refuse piles that contain soluble pyritic materials.

- Sediments -- suspended solids in waters from refuse areas, created by surface erosion of refuse piles and/or solids carryover from slurry ponds.

- Gases -- noxious gases released to downwind areas by refuse pile oxidation and fires.

- Particulates -- fine-grained refuse that, upon drying, may be carried off from exposed piles as silt-sized, airborne particles.

Acid drainage (from active or abandoned disposal sites) is perhaps the most serious of these types of environmental pollution. Numerous small streams in the nation's eastern coal belts have been contaminated with acids, dissolved salts, and heavy metals and are now incapable of supporting aquatic life. In some mountainous areas of eastern Kentucky and southern West Virginia, however, the major water pollution concern is sedimentation. Here, as a result of heavy rainfall and storms, streambeds and adjacent land surfaces have become covered with inert, dark-colored coal refuse sediment which inhibits aquatic life, adversely affects vegetation, and renders the environment unattractive.

Gaseous emissions create significant air pollution problems. In the past, coal refuse fires were sometimes purposely started to produce a hard clinker residue ("red dog") used in road building. However, most coal refuse fires started as a result of heat generated by the chemical oxidation of carbonaceous material in the refuse piles. Again historically, such fires were often allowed to smolder for many years, releasing high-sulfur gases and smoke to the atmosphere. Modern refuse piles seldom have ignition problems, because of present practices which result in less combustible material within the pile and because air permeabilities within the refuse mass are lower.

Airborne particulates from coal refuse disposal areas have sometimes been a concern. The principal dust problems occur with abandoned slurry ponds which have dried out and have not been properly protected from winds. Dust from haul roads near populated areas may also be a concern.

In the past, disposal of coal refuse tended to be an end-of-the-line, least-cost process, and many disposal areas were essentially unplanned and unmanaged. Now, however, for environmental and safety reasons, disposal practices are being significantly improved, as are disposal site reclamation techniques, and careful preplanning for disposal facilities and operations is increasingly being recognized as an essential in the development and utilization of coal resources.

PURPOSE OF THE STUDY

The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) of the U.S. Environmental Protection Agency (EPA) assists in the development and demonstration of new and better ways to control pollution caused by the extraction, processing, and utilization of our nation's energy and materials resources. As part of this responsibility, IERL-Ci sponsored this study, which had as its ultimate objective the development of guidelines for construction, operation, and reclamation of coal refuse piles and slurry ponds, with emphasis on environmental (water and air quality) protection and safety. Included in the guidelines are considerations of refuse haulage, compaction, layering, drainage, soil covering, preparation plant processes, and site reclamation. To secure vital input for the development of the guidelines and other purposes, the study also included extensive air and water quality sampling and analysis programs, so that any detrimental effects caused by the disposal of coal wastes could be identified and evaluated.

SCOPE OF WORK

The scope of work for the study included the following major items:

1. A review of current literature and interviews with key federal, state, and industry personnel to obtain information concerning proper disposal facility design for environmental protection, construction and maintenance methods, and final close-down and reclamation procedures for coal refuse piles and slurry ponds.

2. Selection and field evaluation of eight refuse pile and six slurry pond sites, chosen to be representative of the best technology and construction procedures now in use in terms of reducing water and air pollution

hazards. These sites, all in the eastern United States and in both flat and mountainous terrain, were each visited and evaluated four times, to determine operational procedures and problems and to carry out detailed water and air quality sampling and evaluation programs.

3. Sampling programs at each site to determine flow, acidity, pH, conductivity, alkalinity, sulfate ion, ferric and ferrous iron, aluminum, magnesium, manganese, copper, zinc, lead, cadmium, nickel, and mercury concentrations in waters emanating from the site.

4. Sampling programs at each site to determine air pollution parameters for sulfur and nitrogen dioxide, hydrogen sulfide, carbon monoxide, and methane, and to measure and evaluate particulate emissions and concentrations.

5. Development of the construction and operation guidelines.

6. Preparation of this report, which contains case studies of the sites visited, the data gathered in connection with the study, and the guidelines.

The stability of coal refuse retention embankments is an important consideration in the development and utilization of disposal facilities. Since the Buffalo Creek disaster of February 1972, when a coal refuse dam failure caused 125 deaths and extensive damage in the downstream drainage basin, this aspect of refuse disposal has received considerable national attention. In this connection, the reader is directed to numerous recent studies and government regulations concerning the safe disposal of coal refuse (see, for example, References 1 through 4). Although the scope of work for this study did not include specific evaluations of embankment stability, the study team has drawn on its considerable experience with such problems in developing these guidelines, and where pollution control and stability considerations interact or affect each other, appropriate note has been made throughout the report.

METHOD OF APPROACH

Site Selection and Field Investigations

Selection of the field study sites involved the following steps:

- Development, from the information obtained through the literature search and interviews, of a master list of more than 30 candidate sites.

- Aerial surveys of each site.

- Identification of 18 particularly promising sites, and after owner approval and clearance had been obtained, a more detailed ground inspection of each site.

- Final comparisons and evaluations of sites.

- Final selection of nine sites, which include eight refuse piles and six slurry ponds. These sites, identified throughout the report as Sites A through I, are located in the states of Illinois, Indiana, Pennsylvania, and West Virginia.

The detailed field studies involved making four visits to each site to obtain and develop data on refuse pile and slurry pond construction methods and to conduct air and water quality sampling programs. These visits, carried out over a 12-month period, were arranged so that each site was investigated during both wet and dry weather conditions. For maximum efficiency, and to minimize interference with normal site operations, the construction, water quality, and air quality subteams visited each site together whenever this was possible. However, because the air quality data collection required longer sampling periods than did the water quality program or the construction studies, the air quality team could not always maintain the same schedule as the other groups.

At each site the study team reported to a site staff member who usually accompanied the team during the field investigation. Site conditions were reviewed to identify current and recent refuse disposal areas and to determine if there had been any changes in operating procedures since the last visit. Water quality sample selection points had been determined during the site selection phase of the study; in the study field visits, after wind directions had been determined, the same general locales were also used for the air quality sampling, wherever possible.

Water Quality Sampling

Clean containers, rinsed with distilled water, were used for collection of representative water samples. Samples to be analyzed later in the laboratory were refrigerated to preserve them until the tests could be run. Analyses for properties susceptible to time deterioration were either performed in the field immediately after the samples were taken, or later the same day in the study team's mobile van.

Air Quality Sampling

A four-wheel-drive vehicle was used to transport the air sampling equipment to the selected sampling location. The gasoline-powered generator for the sampler was always operated at least 30 meters (100 feet) downwind of the sampling point. A RAC 5-Gas Sampler was operated for measurement runs of 4, 6, or 8 hours. The sampler was inspected visually every half-hour, to ensure that proper bubbling action and vacuum conditions were present. Wind direction and speed, as well as temperature, were measured at least once an hour.

A battery-powered RAC Midget Impinger, charged with a tared filter paper disc which had been transported in a sealed cassette, was operated for 1 hour at 15 liters per minute. At the end of the sampling period, the disc was replaced in the cassette and resealed.

On the first site visits to all sampling locations, an AID portable gas chromatograph and a recorder (both battery-powered) were taken to the sampling points. Samples of 10 cc of air were collected in a syringe and injected into the chromatograph. However, successful use of this equipment demands a steady base and no air drafts, and attempting to operate the unit in the four-wheel-drive vehicle resulted in unsteady baselines. Therefore, for the second site visits the chromatograph was set up where steady work surfaces were available--for example in an office building, superintendent's office, or bathhouse. Air samples were collected in syringes and taken to the gas chromatograph for injection. This procedure yielded satisfactory results. For the third and fourth visits, the gas chromatograph remained in the air quality subcontractor's offices and the air samples were returned in sealed syringes. Previous tests for CO and CH_4, with analyses performed as much as two weeks after sample collection, had yielded valid results, and the procedure proved satisfactory in this case also.

Development of Guidelines

Information obtained from the literature search, discussions with key personnel, and site visits was compiled and evaluated. To this body of material was added much valuable information drawn from the past experience of the study team members regarding disposal practices and problems in other types of mining operations and in other industries. Although the guidelines are intended primarily for those responsible for the everyday tasks of constructing, operating and reclaiming disposal facilities, considerable information has been included that can be valuable in the planning and engineering phases of facility development. Recommendations and suggestions are provided to indicate how technology used in other fields can be successfully adapted to coal refuse disposal, and examples of acceptable practice are given to illustrate solutions to specific problems.

As far as possible, the guidelines were prepared to conform to current federal and state safety regulations, as well as to environmental protection regulations. Any conflicts that appear to exist between safety and environmental considerations as they relate to construction procedures are noted in the guidelines, for attention and resolution by others, as appropriate.

REPORT ORGANIZATION

Section 2 summarizes the study findings and the guidelines for disposal site development, operation, and reclamation. Also included in Section 2 are some suggestions for possible future research into factors that may have important bearing on pollution control and disposal site development and utilization. Section 3 discusses pollution mechanisms and the physical and chemical properties of coal refuse. Section 4 deals with coal preparation plant processes and procedure, Section 5 with site selection, and Section 6 with conveyance systems for transporting refuse from plant to disposal area. Sections 7 and 8 present construction and operation guidelines for refuse piles and slurry ponds, respectively, and Section 9 provides guidelines for site abandonment and reclamation. Section 10 describes a number of alternative techniques for refuse disposal and pollution control that may be applicable in specific situations.

Detailed descriptions of the study sites, together with the air and water quality data obtained and analyzed in the study, are included in

Appendix A. Appendix B discusses and describes certain standard field and laboratory tests, used to determine the properties of soils, that can be usefully applied to the determination of coal refuse properties. Finally, glossaries of geotechnical terms and coal preparation and relevant water and air pollution terms are provided.

SECTION 2

SUMMARY OF FINDINGS AND POLLUTION CONTROL GUIDELINES

FINDINGS

Construction and Operation of Slurry Ponds and Refuse Piles

Slurry Ponds--

Prior to 1972, coal refuse slurry ponds were often formed by dumping coarse refuse across narrow valleys to create embankments behind which fine refuse was placed hydraulically.[1*] Some of these embankments (dams or dikes) were built haphazardly, without adequate concern for embankment stability or the possibility of overtopping. Also, when an embankment was constructed by dumping refuse down steep slopes from aerial tramways, trucks, or mine cars, the base of the embankment was highly permeable and heavy seepage at the downstream toe was common. If acid-producing refuse was used, the seepage water was acidic and had high concentrations of heavy metal ions.

In addition to acid water drainage through dams or abutment formations, a major slurry pond pollution control concern today is the removal of suspended solids from the pond. Usually, the most troublesome ponds are large, crossvalley impoundments in narrow, steep valleys which lie below large drainage basins. During heavy rains, concentrated, high-velocity runoff waters enter such ponds, reducing pond efficiency and disturbing previously settled solids. Special control provisions are usually required for such situations.

In the construction and operation of slurry ponds, the following general guidelines are of major importance in controlling pollution:

- The minimum practical velocity should be used in discharging slurry into a pond.

- Travel distance of slurry through the pond surface should be maximized, to achieve maximum settling of suspended solids.

- Wherever possible, clarified pond waters should be returned to the preparation plant for reuse.

- Clarified water for return to the plant or for discharge to streams should be removed from points as close as possible to the top water surface of the pond.

---

*For numbered references, see list at end of report.

- Seepage appearing at the downstream toe of the pond retention dam should be collected, treated (if necessary), and released or pumped back to the retention pond.

Refuse Piles--

Drainage from old, acid-producing refuse piles and from erosion of exposed refuse banks is generally a serious water pollution control problem, as is the problem posed by suspended solids from slurry ponds. In the past, coal refuse was usually dumped from trucks or rail cars over steep slopes, or from aerial tramways across narrow, steep valleys. Coarse refuse particles therefore collected near the toes of the slopes, and finer constituents remained near the top of the pile. These loose piles often became unstable if they were used to impound water, or if they were saturated by moisture from heavy rains or from springs within foundation areas. Ground or surface waters passing through the permeable base of an acid-producing refuse pile became highly acidic. The acid waters, in turn, dissolved heavy metals in the refuse, further degrading downstream water systems. Also, surface waters from adjacent areas and from the pile itself would often (especially after heavy storms) erode large gullies in the pile and deposit the sediment downstream.

Another type of pollution problem--one of air pollution--was created by the fact that many old refuse piles that contained large amounts of coal either caught fire or were purposely ignited. Such fires were allowed to smolder, sometimes for years, steadily releasing noxious gases and particulate matter into the surrounding atmosphere.

Today, fortunately, these disposal practices have been largely abandoned, and in the construction and operation of new refuse piles it is relatively simple to guard against these causes of air and water pollution.

In the construction and operation of refuse piles, the following general guidelines are of major importance in controlling pollution:

- Layering and compaction. Proper layering and compaction techniques and operations will help significantly in eliminating particle segregation and in reducing the air and water permeability of the refuse mass.

- Drainage control. Both surface and ground water should be diverted, by means of ditches or subdrains, around refuse piles in order to minimize acid runoff and/or surface erosion. Runoff water from pile surfaces should be directed away from slope faces into ditches or sedimentation ponds. Drainage appearing from beneath piles should be collected and treated, if necessary, before release to the environment.

Water Quality Sampling Program

As indicated in the tabulation below, at the five sites (A through E) where unique inlet and outlet points could be identified it was found that, except at Site A, the pH was lower in the outlet (discharge) waters than in the inlet waters, although, on the average, most differences were relatively small. The tabulation represents averages of the measurements taken on all visits to the sites:

	Site				
	A	B	C	D	E
Inlet point	7.9	7.9	8.0	7.4	7.6
Outlet point	8.0	7.6	7.4	6.6	4.7
Change	+0.1	-0.3	-0.6	-0.8	-2.9

The sampling program also indicated that if oxidation of pyritic material in a disposal area had occurred or was occurring, there were generally increases in pollutant concentrations in the discharge waters as compared with concentrations in inlet waters. Where acidic water was in contact with the refuse, there were increased concentrations of ferrous iron, total iron, sulfates, dissolved heavy metals (copper, manganese, nickel, and zinc), and, depending on the mineral content of the refuse, there were increased concentrations of chloride and the lighter metals such as aluminum and magnesium.

Table 1 indicates average changes in pollutant concentrations based on measurements taken at inlet versus outlet points at Sites A through E. As for the changes in pH values given above, these figures represent averages of all measurements taken on all visits to the sites. Detailed findings for each visit to each site are given in Appendix A, together with details for other sites which did not have both an identifiable inlet point and an identifiable outlet point. Study of Appendix A reveals that the actual concentrations measured varied widely, depending on the site being studied, the time of year for each visit to each site, sampling locations, etc. However the data given in Table 1 appear to give a reasonably valid general picture of the changes in quality caused by the passage of water through coal refuse disposal facilities.

TABLE 1. AVERAGE CHANGES IN WATER POLLUTANT CONCENTRATIONS BETWEEN WATER INLET AND OUTLET POINTS (mg/liter)

Pollutant	Increase or Decrease (-) as Measured at Outlet Point				
	A	B	C	D	E
Ferrous iron	0.03	0.47	0.93	6.83	299.9
Total iron	0.44	15.84	5.10	9.13	351.5
Aluminum	0.32	1.14	0.93	3.10	42.51
Chloride	-8	139	15	None	205
Copper	0.001	0.005	0.012	0.011	0.031
Lead	-0.007	0.024	0.009	0.006	-0.001
Magnesium	4	26	63	9	104
Manganese	0.07	2.50	5.44	1.96	29.31
Nickel	0.001	0.022	0.017	0.021	0.408
Sulfate	75	925	1,426	203	3,037
Zinc	0.01	0.05	0.012	0.06	2.67

Air Quality Sampling Program

All of the sites visited were exercising operating control over airborne particulates; that is, roads were being sprinkled when conditions required, and exposed refuse surfaces were being covered and seeded to prevent wind erosion. Although no samples were taken after a long, hot, dry spell when dust might be at its worst, the particulate measurements were in general quite low. This may have been due in part to the use of watering trucks, but the wet, fine-grained nature of the waste, the layering of material, and the low level of traffic in the refuse areas (four to six trips an hour were usual) are also significant factors.

Table 2, a summary of the data gathered in the air sampling program, presents figures on air pollutant concentrations that represent a composite average for all the sites visited. Detailed measurements for each site are given in Appendix A. Gaseous emissions were well within the normal backgrounds expected for the geographic areas. While four single-day samplings at one specific point cannot be considered ultimate scientific proof, the data obtained suggest that these coal refuse piles and slurry ponds do not contribute significant levels of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), carbon monoxide (CO), or methane (CH_2) to the atmosphere. There was some evidence that the extremely cold weather during the second site visits (in January 1977) caused a lowering of gaseous emissions. However, this may have been a result of decreased industrial activity during this cold period, since much of the mining and associated industrial traffic had almost ceased.

It is obvious from the data collected during this study that proper construction practices, routinely applied, can lead to development of coal refuse piles that produce little or no gaseous emissions. The permeability that led to pyritic decomposition and eventual burning of old, randomly dumped piles does not exist to a significant extent in today's properly layered, compacted sites.

GENERAL CONCLUSIONS

The overall conclusion reached by the study team, from the literature search, interviews, and field study program, is that environmentally acceptable coal refuse disposal facilities can be constructed, operated, and reclaimed using current technology. The potential for pollution of air and/or water can be reduced sufficiently that both fine and coarse refuse disposal sites can be operated during the life of a coal processing plant without deleterious effects on the environment, and the site can later be returned to a productive use. However, the accomplishment of such operation and reclamation is not a simple hit-or-miss proposition. Well-planned utilization of

TABLE 2. AVERAGED AIR QUALITY DATA FOR ALL SITES SAMPLED

	Visit 1	Visit 2	Visit 3	Visit 4	Average
Temperature (^oC)	-5	-24	16	24	
Weather Conditions	---	---	---	---	
Wind Speed (mps)	3.0	2.7	2.0	1.1	
Wind Speed (mph)	6.5	6	4.5	2.5	
Wind Direction	---	---	---	---	
Dust/Particulates (mg/liter)	0.03	0.01	0.03	0.02	0.02
Gases (mg/liter)					
Nitrogen dioxide	0.047	<0.01	0.036	0.028	0.029
Sulfur dioxide	0.078	<0.01	0.036	0.028	0.037
Hydrogen sulfide	0.046	<0.03	0.014	0.012	0.024
Carbon monoxide	1.5	1.3	1.7	1.5	1.5
Methane	3.1	3.0	3.3	3.3	3.2

modern materials and equipment technology, primarily from the construction industry, is necessary in order to achieve pollution-free refuse disposal. The guidelines presented in this report and summarized in the following paragraphs were developed in the context of this general conclusion.

Throughout the guidelines, a continual emphasis on air and water control is obvious. If the introduction of air into the refuse material is controlled, extensive oxidation of pyrites will not occur and significant amounts of gaseous and acidic pollutants will not form. If ground and surface waters are isolated from the refuse material, little or no alteration of these waters will take place.

SUMMARY OF GUIDELINES

This discussion briefly summarizes the guidelines we believe embody the most important considerations associated with proper development, operation, and reclamation of refuse piles and slurry ponds to achieve satisfactory environmental (air and water quality) protection. For more comprehensive discussions of the guidelines, and for details of all the guidelines, the reader is referred to the subsequent sections of this report.

The guidelines follow the sequence of (1) site development, (2) site operation, and (3) site reclamation. There is inevitably some redundancy in using this chronological approach, but since the guidelines are intended for day-to-day use by persons concerned with specific aspects of these three principal life stages of disposal sites, it is believed that this redundancy is acceptable.

Site Selection

- Refuse piles and slurry ponds should be isolated from surface and ground waters.

- If possible, the disposal facility should be so sited that drainage from the refuse pile is diverted into the slurry pond.

- Sites with large drainage areas above the disposal facility should be avoided.

- Cross-valley refuse piles should be avoided.

Preparation Plant Procedures

- Coarse acid-producing refuse from rotary breakers should be mixed with screened refuse or placed in noncritical (central) areas of a refuse pile.

- Preparation plant procedures should be directed at increasing the percentage of fines to reduce air and water permeability of placed and compacted refuse material.

Conveyance Systems

- Acid-producing refuse should not be used as haul-road building material.

- Conveyor belts should be provided with a belt reversal mechanism to avoid spillage on the belt return run.

- Aerial tramway systems should include provisions to preclude unintentional dumping of refuse along tramway routes.

- Slurry pipelines for fine refuse should be located away from landslide areas, and structural sleeves should be provided where the pipeline passes under roadways.

Site Development

- Debris from clearing and grubbing operations should not be disposed of in refuse piles or slurry ponds.

- Where feasible, topsoil from stripping operations should be stockpiled for later use in reclamation.

- At refuse pile sites where there are springs, foundation subdrains to control groundwater should be incorporated.

- Surface waters should be diverted around refuse piles and slurry ponds.

- Where appropriate, sedimentation basins should be planned for and developed downstream from refuse piles.

- A valley-fill refuse pile operation should start at the head of the valley and progress in the downstream direction.

- Cell-type construction methods should be used to dispose of acid-producing refuse on flat or gentle terrain.

Refuse Pile Operations

- Exposed working surfaces of refuse piles, particularly acid-producing refuse, should be kept to the minimum consistent with safe and effective operations.

- Finished refuse surfaces should be reclaimed soon after completion, and in any case during the operational life of the facility.

- Permanent side slopes should be no steeper than 2 horizontal to 1 vertical.

- Top surfaces should be sloped to drain away from side slopes.

- Top surfaces should be graded on an approximately 1-1/2 percent slope.

- The degree of dust control required on haul roads should be determined on the basis of conditions at the specific site.

- Coarse refuse should be placed using methods that will not result in segregation of materials. Refuse should not be dumped or pushed over the faces of steep slopes.

- Truck-placed piles of potentially acid-producing refuse should be leveled and compacted at least once every working shift.

- Lift thickness should be the minimum practical, and in any case should be no more than 60 centimeters (2 feet).

- Nonstructural refuse embankments may be compacted satisfactorily by controlled routing of construction equipment over thin lifts. Loaded scrapers are usually more effective than bulldozers or on-highway trucks for this operation.

- Special, noncritical areas on the site should be designated or reserved for placement operations during inclement weather.

- Operations that cause an increase in the percentage of fines (to a maximum of approximately 15 percent) in acid-producing refuse, and thereby reduce the permeability of the compacted mass, are considered desirable.

Slurry Pond Operations

- If possible, slurry ponds should have "closed" water circuits.

- Slurry ponds with "open" water circuits should have sufficient settling area to meet point source discharge requirements.

- The use of acid-producing refuse in slurry pond retention embankments should be avoided unless seepage waters can be isolated.

- Sites should be inspected at least once a week in order to observe operating conditions and to make any necessary adjustments in pond operations.

Reclamation

- Drainage should be directed away from side slopes except in lined channel sections.

- Refuse pile surfaces should be graded to a minimum slope which will not result in ponding of waters.

- A cover layer of nontoxic clay soils sufficiently thick to promote acceptable vegetative growth should be provided.

- Piles that may contain acid-producing refuse should have an impermeable upper zone of natural soil or refuse extending from the surface to at least 60 cm (2 feet) below the depth of frost penetration, to exhibit percolation of surface water.

Alternative Disposal and Pollution Control Techniques

- Coarse refuse from surface mine operations should, if possible, be buried in the mine spoil piles.

- Refuse disposal in underground mine workings should be undertaken only after detailed evaluations of potential groundwater degradation have been made.

- Slurry ponds should not be constructed in surface mine spoil banks unless groundwater and embankment stability studies indicate it is safe to do so.

SUGGESTIONS FOR FUTURE RESEARCH

At some future date, consideration should be given to selecting a few (two or three) sites where round-the-clock measurements can be made over an extended period of time, using sophisticated recording instruments to determine any significant changes in air or water quality. Attempts might be made to correlate variations in these measurements with dumping practices and other operations. For comparison purposes, simultaneous measurements should be made upwind or upstream from the sites.

Also, although it might prove difficult to secure operator cooperation, investigations of other disposal facilities (including some "hot" or acid piles) that are not utilizing good construction practice might be considered. It must be emphasized that the sites investigated in this project were considered to be following good practices. Comparisons with poorly operated sites might indicate the amount of environmental benefit that could be realized by proper operations at all sites.

Information has been developed by the Illinois State Geological Survey and others on groundwater contamination by trace elements from municipal landfills. Included in this information are some assessments of the effectiveness of various types and thicknesses of clay pond liners in trapping trace elements. With existing knowledge of trace elements in coals and coal cleaning wastes, it may be worthwhile to initiate some research and prototype studies to evaluate the physical effectiveness, comparative environmental impacts, and economics of using clay liners to reduce groundwater contamination from coal refuse piles and slurry ponds.

SECTION 3

COAL REFUSE PROPERTIES

In order to evaluate the effect of a coal refuse disposal area on water and air quality and to suggest effective pollution control guidelines for such facilities, it is necessary to understand the properties of the refuse material, the pollution-forming mechanisms, and the factors which significantly influence these mechanisms. It is not possible to use identical pollution control guidelines for all refuse sites. Some types of refuse have a high pollution potential, so that extensive control measures must be employed. Other types have a lower pollution potential and therefore require less in the way of pollution control. For example, refuse capable of producing acid requires more extensive controls than does nonacid-producing refuse. The properties of both coarse and fine refuse significantly affect construction and operations from the standpoint of pollution control.

An understanding of water and air pollution formation mechanisms and the factors which significantly influence these mechanisms is of paramount importance. Without this understanding, pollution control guidelines would have to be formulated on a trial-and-error basis. This type of approach is extremely risky when dealing with variable material properties and site capabilities and can result in unnecessary cost and unacceptable levels of pollution.

POLLUTION MECHANISMS

There are four principal forms of pollutants associated with coal refuse piles and/or slurry ponds:

Water Pollutants
1. Acid drainage from refuse piles
2. High suspended solids concentrations in drainage water from refuse piles and slurry ponds

Air Pollutants
1. Release of noxious gases from burning refuse piles
2. Dust from active refuse piles and exposed slurry pond deltas

Water Pollution

Acid Drainage--

Acid drainage requires the presence of water, oxygen, and sulfur compounds capable of oxidizing. By far the most common acid-producing sulfide mineral is iron sulfide, but others (copper, zinc, or lead sulfides) may also be associated with the refuse.

The chemical reactions in acid production are believed to be as follows. First, the pyrite is oxidized by oxygen to produce ferrous sulfate and, when water is added to the system, sulfuric acid is produced:[11]

$$\underset{\text{(pyrite)}}{2FeS_2 + 2H_2O + 7O_2} \rightleftharpoons \underset{\text{(ferrous sulfate + sulfuric acid)}}{FeSO_4 + 2H_2SO_4}$$

Subsequent oxidation of ferrous sulfate produces ferric sulfate:

$$4FeSO_4 + 2H_2SO_4 + O_2 \longrightarrow 2Fe_2\ (SO_4)_3 + 2H_2O$$

The reaction may then proceed to form a ferric hydroxide or basic ferric sulfate and more acid:

$$Fe_2(SO_4)_3 + 6H_2O \longrightarrow 2Fe(OH)_3 + 3H_2SO_4$$

$$Fe_2(SO_4)_3 + 2H_2O \longrightarrow 2Fe(OH)(SO_4) + H_2SO_4$$

A low pH water is produced (pH 2 to 4.5). At these pH levels, the heavy metals such as iron, calcium, magnesium, manganese, copper, and zinc which are also associated with the refuse are more soluble and enter into the solution to further pollute the water.

Not all pyritic material is readily oxidizable. Caruccio[9] has shown that finer-grained pyrites (2 - 15 microns) rapidly decompose when exposed to the atmosphere, while coarse pyrite particles (larger than 50 microns) remain relatively stable. In addition, there may be other chemical constituents (e.g., lime) in the refuse which tend to neutralize the acid produced.

Several other variables can influence the amount of acid produced:

1. The amount of soluble impurities in the refuse pile
2. The distance water travels through the pile
3. The oxidation rate of the pyrite material
4. The time water is in contact with the soluble materials
5. Temperature (the lower the temperature the lower oxidation rate)

Suspended Solids--

Suspended solids in waters leaving a refuse area are caused principally by surface erosion of refuse piles and insufficient settling of solids in slurry ponds. Erosion is caused by water moving over a material at a velocity sufficient to carry off particles of material.

The principal variables that affect the settling of suspended solids in a slurry pond are the particle size and specific gravity of solids, the kinematic viscosity of the fluid, velocity of slurry movement through the pond, and length of free-water surface between the slurry discharge point and the clear water decant structure. The settling velocity of a suspended solid, which varies approximately with the square of the particle diameter, is the most significant variable with respect to efficiency of settling basins. Most fine refuse is silt-sized, with varying amounts of sand. The specific gravity of fine coal refuse normally ranges from 1.6 to greater than 2.4, depending on the composition of the materials. This is substantially less than most soils, which have specific gravities near 2.6 to 2.7.

The primary variable that affects the kinematic viscosity of water is temperature. The viscosity of water at 1°C is about twice the viscosity at 30°C. Ponds are therefore much less efficient in the winter than in the summer. The velocity of the fluids through a settling pond affects the time available for particle sedimentation and the drag forces, or resistance to downward movement, on the settling particle. The lower the velocity, the less the turbulence and the greater the efficiency of the pond. The greater the length of the slurry path over clear water, the more time there is avilable for the particles to settle.

Air Pollution

Gases from Refuse Pile Fires--

Ignition of combustible material within a refuse pile, and the resulting release of noxious gases, can be initiated in several ways. These include spontaneous combustion, careless burning of trash on or near the bank, grass, brush, or forest fires, camp fires left burning, and intentional ignition to create residue ("red dog") which may be used for road base or other foundation purposes.

All these mechanisms except spontaneous ignition are the result of human activities and must be controlled by education and site security. Spontaneous ignition occurs when the heat generated by the oxidation of organic material (including coal) and/or pyrite is sufficient to cause ignition. For this to occur, sufficient air must enter the refuse dump to oxidize the coal and other combustible materials, but the air must be insufficient to carry away the heat generated during the oxidation. In studies by England's National Coal Board[2] it was determined that temperature, coal rank, presence of pyrites, moisture, voids ratio, and specific surface influence spontaneous combustion.

Temperature. The combination of atmospheric oxygen with carbonaceous material is exothermic (heat is given off). If the generated heat is not dissipated, the oxidizing and heating effects become cumulative and the temperature rises rapidly, increasing the rate of oxidation still more. Coal and carbonaceous materials may oxidize in the presence of air at temperatures far below their ignition points. Cellulose materials, such as wood, straw, jute, paper, and cardboard, do not react appreciably with oxygen until they approach their ignition temperatures, in the range of about 260°C to 300°C. However, at ambient temperature and in the presence of moisture, these materials are subject to spontaneous heating through the action of certain microorganisms. For this reason, and because they ignite easily, materials containing cellulose should not be deposited in or on coal refuse piles.

Coal Rank. In general, lower rank coals are more reactive and hence more susceptible to self-heating than higher rank coals.

Presence of Pyrites. Iron pyrite (FeS_2) is oxidized at normal temperatures by moist air to form sulfate and sulfuric acid. This reaction is highly exothermic. Pyrite, if present in sufficient proportion, and particularly when finely divided and associated with carbonaceous matter, increases the tendency toward spontaneous combustion in coal refuse piles. When heating occurs, the oxidation of pyrite and organic sulfur in the coal will form sulfur dioxide, and if there is insufficient air for complete oxidation, hydrogen sulfide will be given off. The characteristic smells of these gases sometimes provide a means of detecting a burning area or hot spot.

Moisture. At relatively low temperatures, an increase in free moisture increases the rate of spontaneous heating. High inherent moisture, a feature of low rank coals, is, paradoxically, indicative of a tendency to spontaneous heating. The presence of free moisture is essential for the oxidation of pyrite, and in the presence of pyrite, moisture accelerates oxidation and contributes to heating.

Voids Ratio and Specific Surface. The ease with which air passes through refuse containing carbonaceous material determines the rate at which heat generated by oxidation is carried away. With large-size material and larger air voids, the movement of air is usually sufficient to carry away any heat generated by oxidation and to cool the material. With well-graded or fine material with small air voids, the air remains stagnant and the heat generated is retained in the mass, but when the available oxygen is consumed, heating stops. With intermediate gradings and voids the conditions for spontaneous heating are ideal, and the heated parts may form hot spots and eventually break into flame. Another important factor in the oxidation process is the specific surface of the carbonaceous materials exposed to air. The rate of oxidation generally increases as the specific surface increases, i.e., as the size of particles decreases.

Burning refuse piles are largely confined to old deposits which contained considerable combustible material and which were dumped in large, loose piles. Modern refuse piles seldom have ignition problems, because there is less combustible material in the pile and because air permeabilities in the refuse mass are lower.

Dust--

Dust is the transport by wind of small particles (less than 1 mm in diameter). Such particles have a lower falling velocity than the upward velocity of the turbulent winds and are carried in eddies that move in all directions. Dust from dry refuse piles and associated haul roads can be a pollution source because vehicular traffic causes the fine components of the refuse to be physically lifted up from the surface and carried away by winds. Dust can also be a problem on slurry ponds which have large deltas of exposed fine refuse above the pond level.

Winds are usually classified by speed, direction, and turbulence. Surface winds are turbulent for all velocities over approximately 2 to 3 mph.

However, wind velocity decreases substantially toward ground level because of frictional drag. Since soil erosion is strictly a surface phenomenon, the wind speeds and turbulence to be considered in connection with soil erosion are those at, or close to, the ground. This turbulence is usually observed as gusts that cause localized soil disturbance. The minimum threshold velocity required to start soil movement varies with grain size. The threshold velocity for grain sizes from 0.1 to 0.15 mm is 8 to 9 mph at 15 cm (6 in.) above the ground. Above and below these sizes threshold velocity increases. The range of threshold velocity for all grain sizes is from 13 to 30 mph at a height of 30 cm (1 ft) above the surface.

Wind separates the soil into two fractions by removing and redepositing elsewhere the highly erodible grains, leaving wind-stable particle sizes behind, and wind also provides the energy for saltation--the process of alternately lifting and dropping particles. The amount of soil eroded by wind depends on wind velocity, height of protruding nonerodible particles, and distance between protrusions. The height that slows wind velocity to 9 mph or lower is called the "critical height," and the ratio of height of projection to the minimum distance between projections that will prevent the movement of erodible fractions is called the "critical surface-roughness coefficient." These are the most important factors to be taken into account when considering the interactions of winds and soils.

PROPERTIES OF COARSE REFUSE

The physical and chemical properties of coarse refuse have received substantial attention in the past. Most investigations of physical properties have been directed at evaluating the suitability of materials for use in engineered fills or at determining the safety or stability of coarse refuse in piles or embankments to retain slurry ponds. Work on chemical properties of coarse refuse has been primarily associated with establishing suitable plant growth directly on exposed piles and to a lesser extent on pollution control.

As indicated in the list below, physical properties refer to both index and engineering properties; these reflect the physical makeup of the soil-like materials. The materials may consist of rock particles, gravel, sand, silt, or clay, or they may be processed materials such as coal refuse. Regardless of the type, their physical properties must be determined on the basis of experience and/or field and laboratory tests, in order to determine the physical makeup and engineering characteristics of the material.

PHYSICAL PROPERTIES OF COARSE REFUSE

Index Properties	Engineering Properties
Grain-size distribution	Moisture-density characteristics
Plasticity	Relative compaction and density
Specific gravity	Permeability
Parent material	Compressibility
Soil structure	Static and dynamic shear strength
Ignition point tests	Moisture-volume changes

Field and laboratory tests used to determine the physical properties of refuse are described in Appendix B. An important consideration in such testing is degradation of the material during the sampling, transporting, and testing stages. Coal refuse is commonly composed of soft, clay-shale particles which readily break down into smaller particles when exposed to air and/or water and when mechanically handled and tested. As a consequence, laboratory testing of degraded refuse materials may yield results which are not representative of the actual physical properties in the field. Such results can be extremely misleading. For example, if permeability tests are performed on reconstituted coarse refuse samples compacted in a mold with an impact hammer, some of the gravel-sized particles may have broken down into finer sizes. As a result, the laboratory permeability value may be substantially less than the actual field value. Therefore, the physical properties of refuse materials which are affected by particle size degradation should be determined by field rather than laboratory testing, if possible.

The physical properties data presented herein were compiled from test results obtained by W. A. Wahler & Associates during research work performed for the U.S. Bureau of Mines and the Mining Enforcement and Safety Administration, and during investigatory and analytical work for coal mining companies. Several other technical references were reviewed and, where available, appropriate data have been included. Two references in particular, "Tentative Design Guide for Mine Waste Embankments in Canada," prepared for the Mines Branch Mining Research Center, and "Spoils Heaps and Lagoons," a technical handbook prepared by the National Coal Board of England, were useful in this connection.

Index Properties

Grain-Size Distribution--

The gradation results for 128 samples of coarse coal refuse are presented on Figure 1 in the form of a range of all samples tested, a range encompassing 70% of all data, and the arithmetic average. These data represent gradation results from burning and nonburning refuse dumps which were constructed by aerial tram or random truck dumping methods. While these data have a rather broad range, elimination of the upper and lower 15 percentiles reveals a reasonably narrow range for the remaining 70%. The heights of the refuse dumps from which the data were obtained range from tens to several hundreds of feet. Similar data on grain-size distribution were obtained from the National Coal Board of England and the Canadian Mining Research Center.

The effects of particle breakdown due to weathering and handling are shown on Figure 2, which presents the average gradation results for "fresh" coal refuse from three sites, as well as the average gradation for the 128 samples referenced on Figure 1. These samples were obtained directly from dump surfaces within one day after being deposited there. Comparing the average gradation results for all samples with those of the fresh material, it is observed that the material as originally deposited on the dumps was classified as a well-graded gravel with more than 60% of the material coarser than the #4 sieve and less than 10% finer than the #200 sieve. The gradation results for the average of all samples tested, however, indicate that less than 40% of the material is coarser than the #4 sieve and approximately 15%

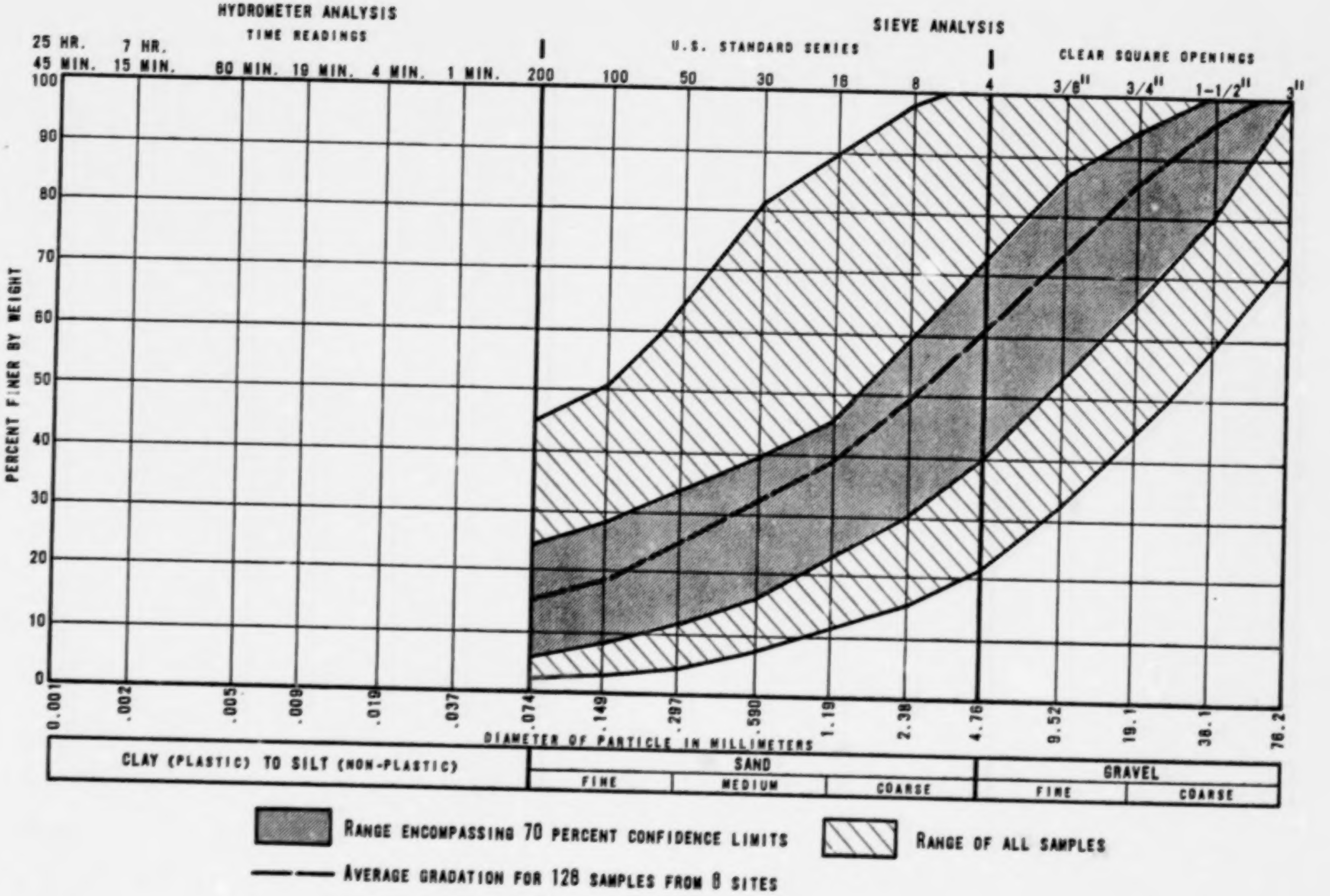


Figure 1. Gradation summary, coarse coal refuse.

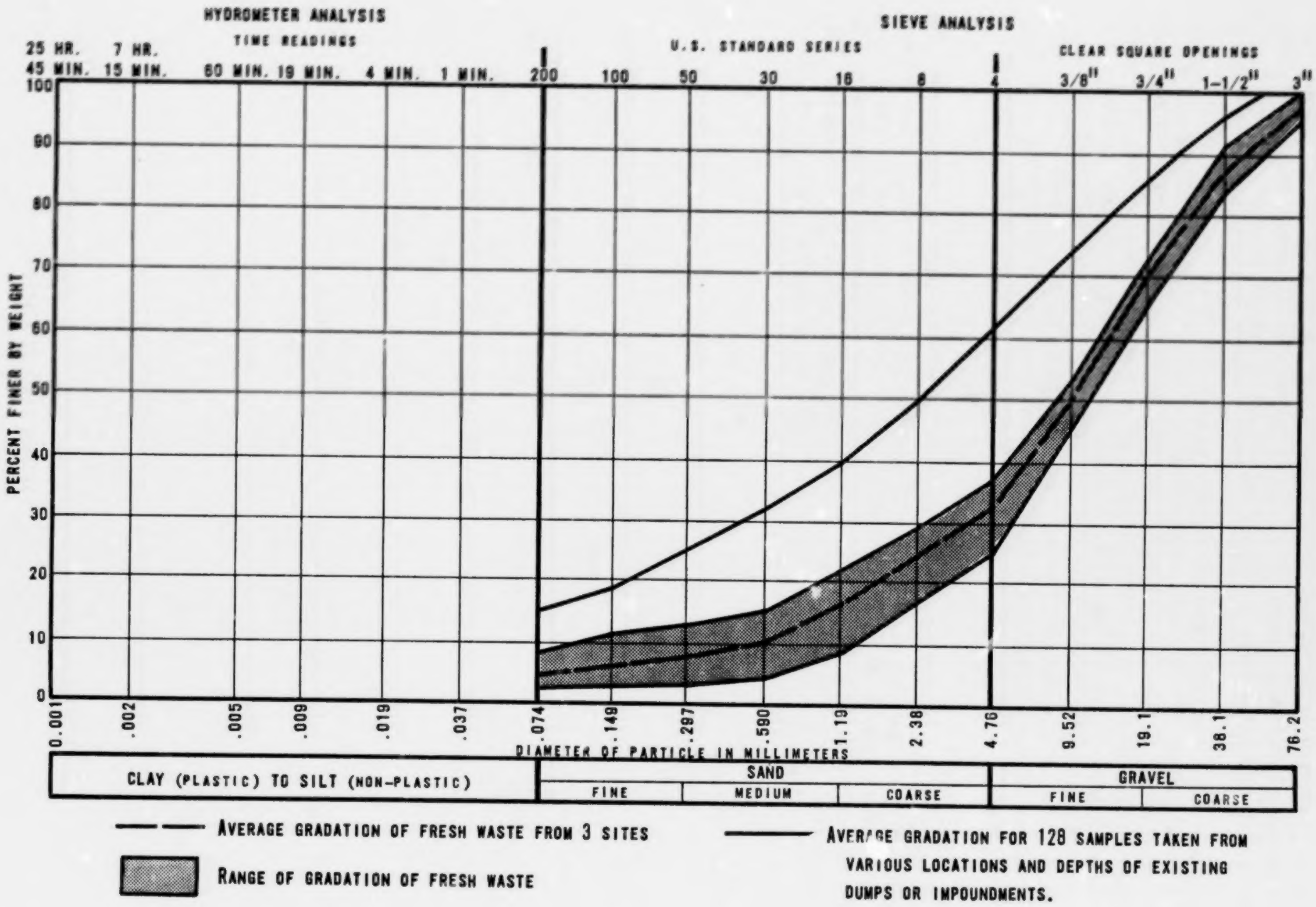


Figure 2. Gradation summary, fresh coarse coal refuse.

of the material is finer than the #200 sieve. The roughly parallel nature of the two average gradations shown on Figure 2 below the #4 sieve indicates that the majority of the breakdown is occurring on the plus #4 particle sizes.

The grain-size distribution of coarse refuse can vary significantly depending on a number of factors, including the nature of the coal seam and the materials above and below the seam, mining methods, preparation plant procedures and efficiencies, handling and placement methods, compaction, and age. Because of the importance of grain-size distribution and the many factors that affect it, periodic testing of refuse gradation is advisable during the operational life of the disposal area. It is suggested that samples for testing be obtained after refuse placement, at depths of 90 to 120 cm (3 to 4 ft) below the surface.

Atterberg Limits--

Atterberg limits are index properties which may be used in evaluating the fine (smaller than the #40 size sieve) component of coarse refuse. The majority of the coarse refuse material is nonplastic. Seventeen samples out of some 150 samples tested in the laboratory exhibited some plasticity (Figure 3). The averaged results indicate a liquid limit of 30% and a plasticity index of less than 10%. It appears, therefore, that the fines in coarse refuse are predominantly silty.

Specific Gravity--

Specific gravity is defined as the ratio of the unit weight of a substance and the unit weight of water at 4°C. As an index test, specific gravity is somewhat indicative of the durability of a material. Materials with low specific gravities are likely to break down and change their physical properties over time. Materials with high specific gravities normally do not deteriorate rapidly. Specific gravity also affects the unit weight of a material. Other factors being equal, a material with a low specific gravity has a low unit weight. Specific gravity values for coarse coal refuse range from about 1.6 to greater than 2.4, depending upon the composition of the materials. The specific gravity results for 37 coarse refuse samples are presented below.

SPECIFIC GRAVITY OF COARSE COAL REFUSE SAMPLES

No. of Samples	Range of Specific Gravity
3	1.60 - 1.80
9	1.81 - 2.00
13	2.01 - 2.20
4	2.21 - 2.40
8	> 2.40
Average Specific Gravity	2.14

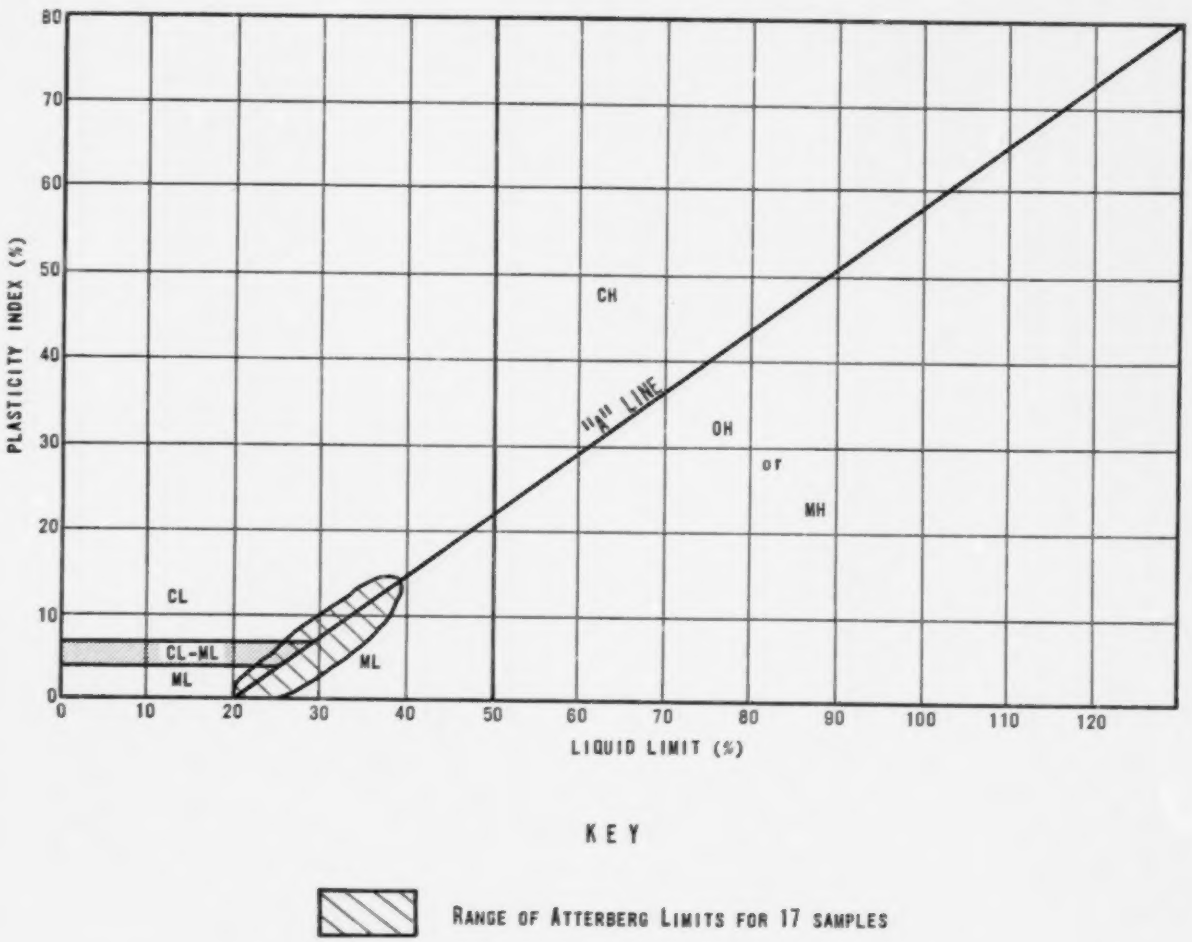


Figure 3. Atterberg limits, coarse coal refuse.

Most soils have specific gravities which range from 2.5 to 2.9, with an average value of about 2.7. Coarse refuse is therefore considered to have a low specific gravity.

Parent Material--

Parent material refers to the basic rock type--such as shale, sandstone, limestone, or coal--from which the refuse was derived. Most coal refuse comes from soft rock formations, principally shales. Some of these shales break down partially into smaller particles when exposed to the atmosphere and when placed and compacted in a fill. The breakdown of coarse particles into finer particles is important because it affects the engineering properties of the material.

Investigations by W. A. Wahler & Associates[1] and by the University of West Virginia[5] have confirmed the degradation effect caused by weathering. Table 3 shows the effect of weathering on shale refuse from four West Virginia mines. The "fresh" refuse was taken directly from the refuse hopper as it came from the preparation plant. Old refuse was taken from the refuse pile where it had been exposed for 18 months to 30 years.

Engineering Properties

Natural Water Content and Dry Density--

The natural water content and dry density of coarse coal refuse depend on the method of disposal used and on whether the dump is burning. In-place dry density and water content data obtained from eight sites in West Virginia are summarized on Figures 4 and 5, respectively. These data were obtained from both field and laboratory tests. Water content values (Figure 5) ranged from 2% to 28%, with approximately 90% of all the data falling between 4% and 16%. The arithmetic average of the natural moisture content, based on dry weight, for the 141 samples tested was 10.4%. In-place dry density values (Figure 4) had a wide range, from 961 to 1,858 kg/m^3 (60 to 116 lb/ft^3), with about 84% of the results greater than 1,281 kg/m^3 (80 lb/ft^3). The arithmetic average for the 134 samples was 1,448 kg/m^3 (90.4 lb/ft^3).

Compaction--

A number of laboratory compaction tests are used by the industry, and each one gives appreciably different results. The choice of which test to use is based principally on the proposed use of the material (i.e., general fill, highway base, earth dam) and depends also on the personal preference of the investigator. It is therefore difficult to summarize the compaction data available in the literature statistically.

In an extensive survey of coal refuse piles in the eastern part of the nation, W. A. Wahler & Associates performed 38 compaction tests on coarse coal refuse in accordance with ASTM D1557-70, modified to 768 joules/m^3 (20,000 ft-lb/ft^3) compactive energy.[1] The results (presented in Table 4) show a broad range of maximum laboratory densities--from 1,221 to 1,981 kg/m^3 (76.2 to 123.7 lb/ft^3). A somewhat progressive increase in maximum density can be seen when the data are grouped according to ranges of specific gravity. The major factors influencing the scatter of data are the differences in specific gravity and gradation for the individual samples.

TABLE 3. EFFECTS OF WEATHERING ON COARSE REFUSE

Test or Property	Philippi Samples			Humphrey Samples		Shoemaker Samples		McElroy Samples	
	Fresh-Coarse	Fresh-Fine	Old	Fresh	Old	Fresh	Old	Fresh	Old
Grain Size (%)									
Gravel (#4-3")	64.3%	8.7%	27.1%	57.0%	41.4%	76.0%	61.3%	89.4%	50.6%
Sand									
Coarse (#10-#4)	3.0	35.0	20.2	25.4	12.6	16.3	18.4	5.2	20.4
Medium (#40-#10)	4.9	43.3	23.7	15.8	9.6	3.3	10.6	2.9	13.8
Fine (#200-#40)	12.2	10.5	11.6	0.7	16.6	1.2	3.5	1.7	5.6
Silt (0.005 mm-#200)	10.9	1.1	6.5	0.7	18.9	1.6	2.9	0.8	4.9
Clay (<0.005 mm)	4.7	0.4	10.6	0.4	0.9	1.6	3.3	--	4.7
Atterberg Limits									
Liquid limit (%)	NP	NP	31.2	NP	36.0	30.6	34.2	28.4	36.8
Plasticity index			5.2		11.0	10.1	15.9	8.4	13.1
Shrinkage limit (%)			24.8		22.4	15.2	17.8	19.0	16.3
Unified Soil Classification	GM	SW	SW-SM	GP	SC	GP	GP-GC	GW	GP-GC
Specific Gravity of Solids (G_s)(gm/cc)	1.68	1.98	2.0	2.22	2.41	2.52	2.63	2.45	2.61
Ignition Loss (% oven dry wt)[a]	42.6	--	49.3	29.0	27.2	17.3	15.0	16.2	18.9
Ash	57.4	--	50.7	71.0	72.8	82.7	85.0	83.8	81.1

---

a. 24 hours at 600°C.

Source: Reference 5

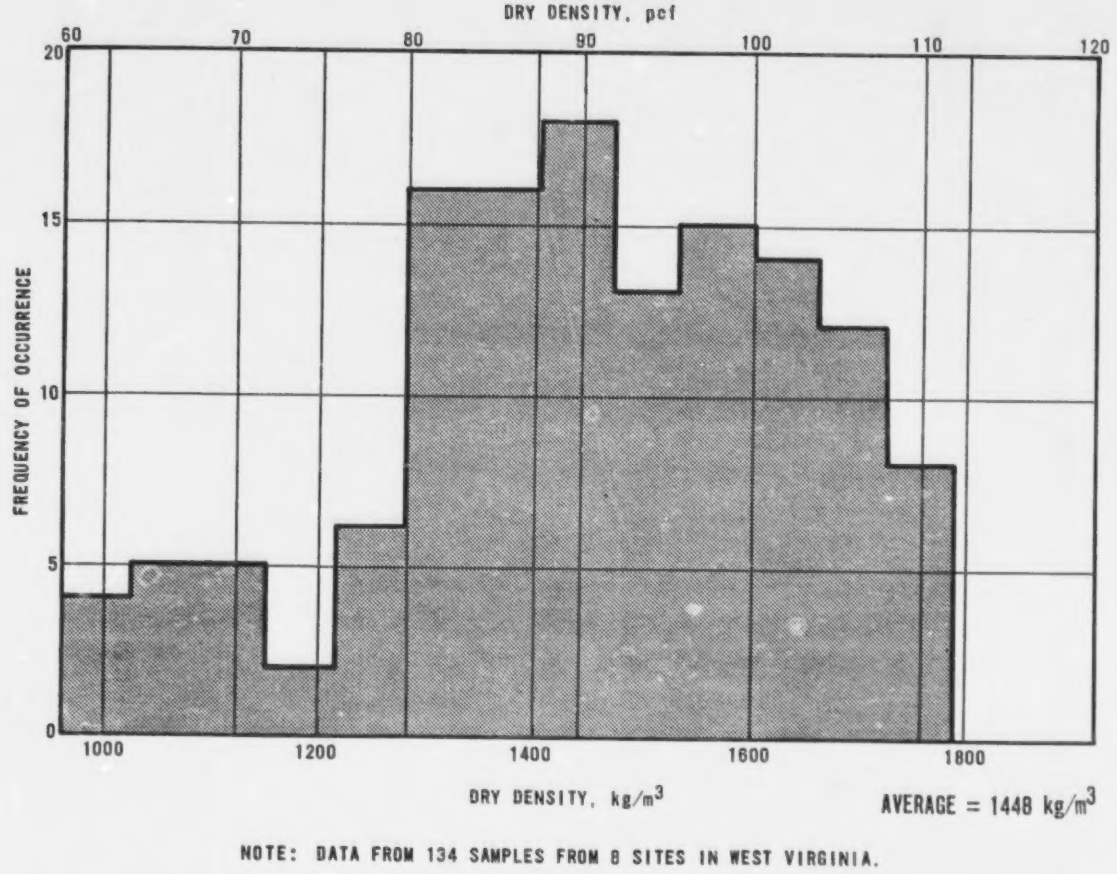


Figure 4. In-place dry density, coarse coal refuse.

Compaction tests are used in evaluating the unit weight and moisture content of embankments such as dams, roadway bases, and other structural fills. In construction control of structural fills, it has been traditional to specify the percent compaction (commonly 95%) by comparing the maximum dry density determined in the fill with the dry density determined in the laboratory. This practice is not in uniform use in refuse disposal.

Quantitative data on the effect of field placement and compaction of coarse refuse are lacking. Nevertheless, it is reasonable to assume that some particle breakdown does occur in the placement and compaction of coarse refuse.

Permeability--

The permeability characteristics of coarse coal refuse materials are evaluated by reviewing field and laboratory test data. Values of the coefficient of permeability range between 10^{-2} and 10^{-6} cm/sec, with a typical value

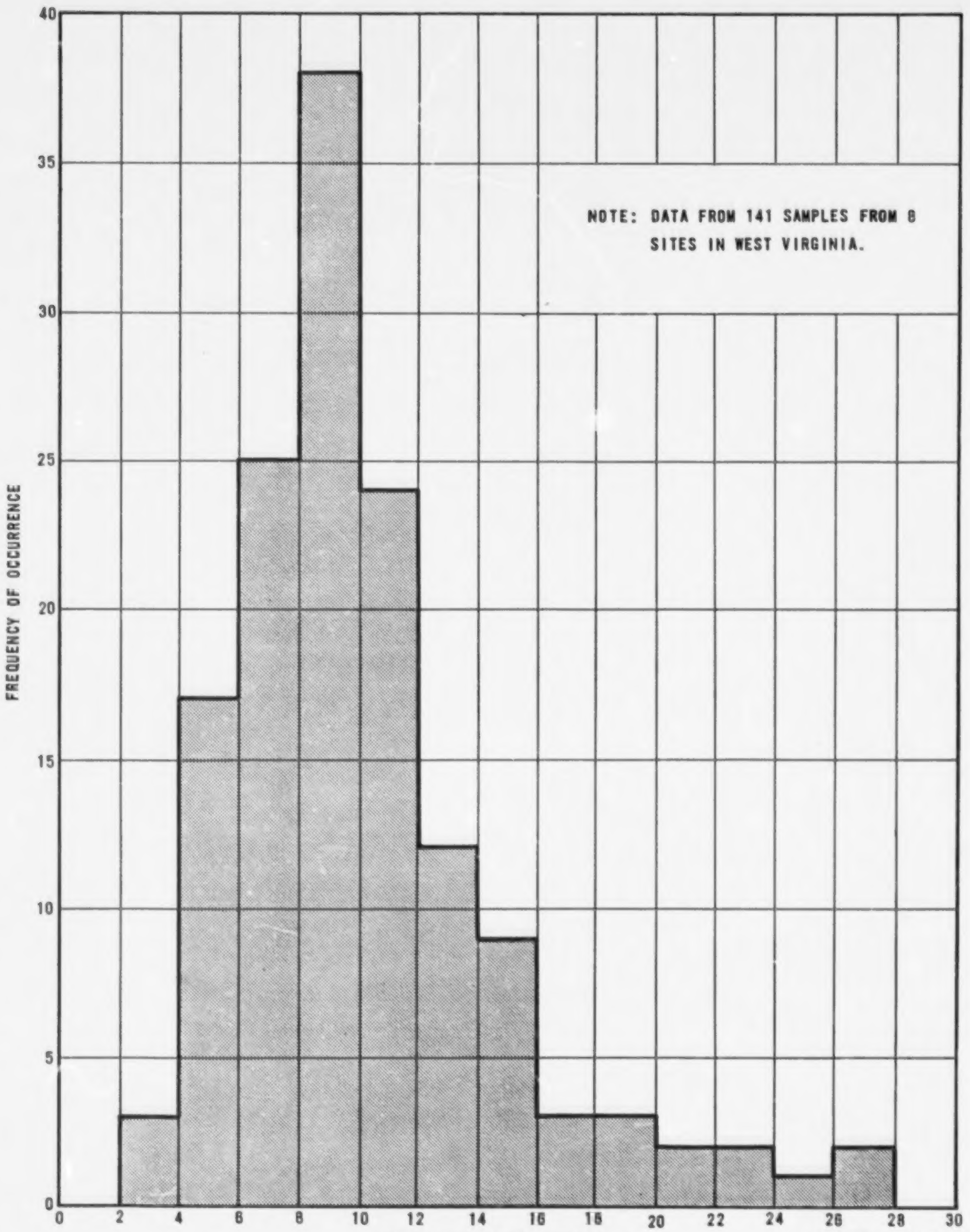


Figure 5. Natural moisture content, coarse coal refuse.

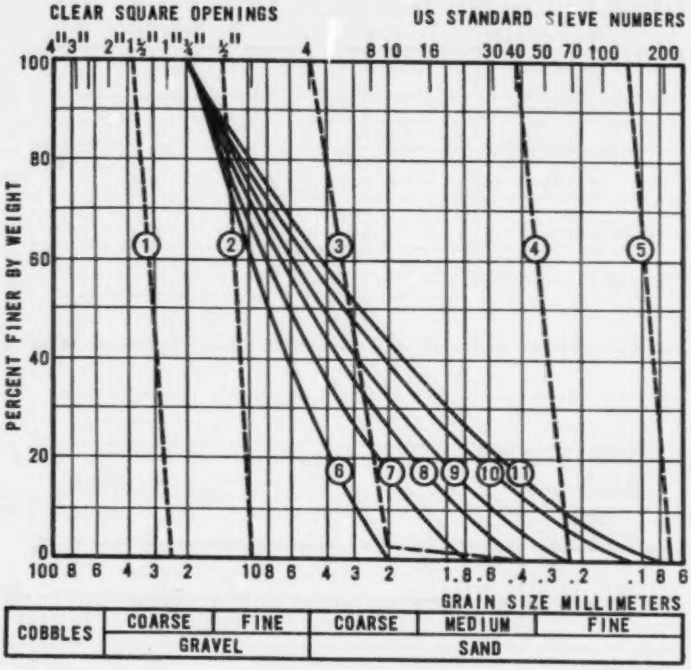
TABLE 4. COMPACTION CHARACTERISTICS OF COARSE COAL REFUSE

No. of Tests	Specific Gravity Range	Laboratory-Compacted Maximum Dry Density						Optimum Moisture Content (%)		
		Low		High		Average				
		Kg/m^3	Lb/ft^3	Kg/m^3	Lb/ft^3	Kg/m^3	Lb/ft^3	Low	High	Average
3	1.75 - 1.80	1,221	76.2	1,530	95.5	1,405	87.7	7.5%	19.5%	12.6%
8	1.81 - 2.00	1,440	89.9	1,672	104.4	1,579	98.6	7.5	14.0	10.5
13	2.01 - 2.20	1,451	90.6	1,738	108.5	1,642	102.5	6.5	11.5	9.7
14	2.21 - 2.63	1,477	92.2	1,981	123.7	1,752	109.4	7.5	15.0	11.7

Source: Reference 1.

of 10^{-4} cm/sec. The permeability of refuse is the most important physical property with respect to air and water pollution control. The significant variables that influence the permeability of coarse refuse are grain size and compaction. (Compaction of a well-graded refuse reduces the continuous voids in the material; this in turn reduces permeability.)

Well-graded refuse with an optimum percentage of fines has a very low permeability, while uniformly graded coarse refuse with little or no fines has a high permeability. Figure 6 shows the influence of grain size on permeability for clean, coarse-grained materials. The more well-graded the material, the less the permeability. This is due to the reduction in voids through which fluids can pass. For example, refuse with a grain size similar to that of curve 6 on Figure 6 is approximately 200 times more permeable than refuse similar to curve 11.



COEFFICIENT OF PERMEABILITY, K

CURVE	m/min	ft/min
①	22.5	73.7
②	17.3	56.9
③	1.65	5.41
④	0.04	0.13
⑤	.003	.01
⑥	.63	2.08
⑦	.55	1.81
⑧	.21	0.70
⑨	.07	.22
⑩	.02	.08
⑪	.003	.01

Figure 6. Effects of grain size on permeability of clean, coarse-grained materials.

Other grain size characteristics that influence the permeability of coarse-grained materials are the percentage and type of fines passing the #200 sieve (see Figure 7). A well-graded, coarse-grained material with 15% silt or clay fines is approximately 100,000 times less permeable than coarse-grained material with no fines. As the percentage of fines is increased beyond about 15%, the effect on permeability becomes less pronounced.

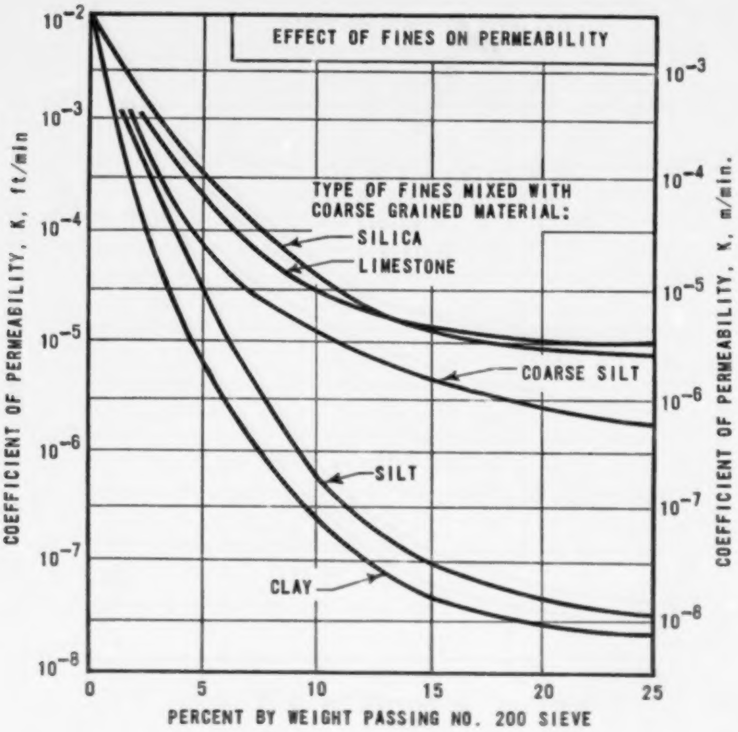


Figure 7. Effects of fines on permeability of coarse-grained materials.

Compressibility--

The compressibility characteristics of coarse refuse are difficult to investigate in the laboratory. However, in the W. A. Wahler & Associates' studies just cited,[1] evaluations were made of data from saturated, isotropically consolidated triaxial test samples and from one saturated anisotropically consolidated triaxial sample, whose average initial densities ranged from 1,362 to 1,522 kg/m^3 (85 to 95 lb/ft^3). A range of volumetric compression of 3% to 6% was observed for the anisotropically consolidated samples as compared with 9% for the isotropically consolidated samples at 689 x 10^3 Pa (100 psi) maximum principal effective stress. Because of the relatively high permeability of the coarse material, the time delay associated with the consolidation process is extremely short. In other words, straining within a saturated embankment due to a load application would occur very rapidly. Also, the magnitude of the volumetric compression is considered high compared to an average value of less than 3% volumetric strain at 689 x 10^3 Pa (100 psi) for a well-compacted material with gradation characteristics similar to those of coarse coal refuse.

Shear Strength--

Shear strength parameters of the coarse refuse material were determined from laboratory triaxial tests performed under ICU test conditions on 51 laboratory-fabricated and undisturbed tube samples. The parameters, based on effective stresses, ranged from 34° to 41°, with essentially zero cohesion intercept. It is interesting to note that the dry densities of the triaxial samples varied considerably, and yet the effective stress friction angles varied less than 7°. The influence of the scatter in density is more reflected in the shear strength parameters based on total stresses; friction angle ranged from a value less than 15° to approximately 20°, with 48.3×10^3 Pa (7 psi) cohesion intercept.

The relatively high shear strength values of the coarse refuse materials indicate one very important point. Since these materials are inherently quite strong compared to other construction materials, if proper construction techniques are utilized, a dam or dump made with these materials, utilizing current earth dam design standards, could provide a safe, adequate structure.

Chemical Properties

When the coal was geologically formed, various salts, minerals, and trace metals were concentrated in the coal seam and in the rocks above and below the seam. These impurities were, for the most part, locked into the ground due to the physical condition associated with the coal seam. The air and water permeability of the geological environment, was, as a whole, relatively low except where the coal outcropped. The mining and processing of coal changes the physical makeup of the environment and in many cases exposes the various chemical components of the coal seam directly to the atmosphere. The processing of coal tends to concentrate many of these impurities in the refuse. Under certain conditions, the impurities may be leached from the refuse in sufficient quantities to cause objectionable environmental effects.

Only limited data are available in the literature concerning the chemical properties of coarse coal refuse. However, in one survey of 79 refuse piles in Pennsylvania, Davidson tested the chemical properties of the actual refuse.[7] The results are summarized in Table 5.

From his study, Davidson concluded that there was no correlation between the physical or chemical properties of the refuse and the coal seam being mined or with the depth from which the samples were collected.

While data concerning the chemical properties of coarse refuse are somewhat scarce, there are more data available on the chemical properties of effluent discharges from refuse piles. Martin[8] has compiled a substantial amount of chemical data on seeps and direct runoff from refuse piles in Pennsylvania, West Virginia, Kentucky, Indiana, and Illinois. The results are shown in Table 6.Martin concluded that the water pollution load from refuse piles varied greatly, depending on the coal seam mined, the mining methods, preparation processes, and pile construction. He found that the central portion of the eastern coal province (southern West Virginia and eastern Kentucky) apparently produced less acidic runoff than did the other areas of the eastern and interior provinces.

TABLE 5. SELECTED CHEMICAL CHARACTERISTICS OF SAMPLES OF UNDERGROUND MINE REFUSE

	SEAM						
Range	A	B	C	C'	D	E	Pittsburgh
				pH			
Average	3.1	3.4	3.0	3.5	3.8	3.8	3.6
Median	2.9	3.2	3.1	3.3	3.6	3.4	3.1
Highest	4.1	6.8	3.4	4.4	6.1	9.4	7.7
Lowest	2.6	2.2	2.4	2.6	3.0	2.4	2.4
				Exchangeable acidity (meq H^+/100 gm)			
Average	8.5	9.8	6.4	5.1	6.4	8.0	8.8
Median	5.8	7.0	4.4	4.2	6.7	6.5	9.1
Highest	22.2	113.0	15.6	10.5	14.5	39.0	33.4
Lowest	2.3	0.6	3.4	2.4	2.4	0.4	0.3
				Conductance (mmho/cm)			
Average	0.87	1.88	1.51	0.32	0.31	1.61	2.30
Median	0.75	0.61	0.64	0.21	0.22	0.86	2.48
Highest	2.23	20.20	5.06	1.30	1.71	8.57	6.75
Lowest	0.22	0.12	0.27	0.10	0.08	0.12	0.12
				Sulphates (ppm SO_4)			
Avearge	1,209	3,395	12,097	873	739	4,643	10,953
Median	657	1,087	4,688	788	520	1,050	6,937
Highest	3,227	26,575	50,438	2,000	3,037	30,150	30,150
Lowest	235	62	362	235	37	62	270
				Phosphorus (ppm P)			
Average	0.2	1.3	0.6	1.0	1.8	3.1	6.7
Median	0.2	0.9	0.7	1.0	0.3	1.4	6.1
Highest	1.0	15.5	1.0	2.2	16.5	16.5	21.0
Lowest	0.0	0.0	0.2	0.3	0.0	0.0	0.7
Number of Samples	10	88	8	16	26	50	70

Source: Reference 7.

TABLE 6. ANALYSES OF EFFLUENTS FROM REFUSE FROM MINES IN FIVE EASTERN U.S. STATES[a]

Sample	pH	Conductivity	Total Acidity	Alk.	SO_4	Na	Mg	Al	K	Ca	Mn	Fe	Ni	Cu	Zn
PENNSYLVANIA[b]															
Eastern Pennsylvania (anthracite)															
P1	3.0	4,400	689	-	3,000	100	250	87	4.8	340	50	30	1.7	0.14	2.8
P2	4.1	3,000	250	-	1,600	60	140	50	15	180	90	0.6	1.1	0.18	2.4
P3	4.5	1,300	25	-	500	4	45	10	2.6	100	4	1.2	0.3	0.04	0.5
P4a	5.8	130	6	5	60	6	2	0.9	0.5	13	0.4	0.1	-	-	-
P4b	4.3	200	25	0	75	6	3.4	3.0	0.5	13	0.9	0.7	-	-	0.1
Western Pennsylvania															
P5a	7.5	600	0	160	106	16	35	1.0	2.2	70	0.01	0.1	-	-	-
P5b	7.5	660	0	170	106	16	35	1.0	2.5	70	0.1	0.1	-	-	-
P6	3.6	925	325		420			28			4.5	5.8			
P7	2.1	10,400	23,100		27,500			948			545	3,758			
P8	3.5	3,700	1,300		1,485			40			9.1	175			
P9	2.2	10,000	24,400		29,750			668			69	3,732			
P10	3.1	13,600	34,300		40,500			999			63	6,168			
P11	2.6	5,600	6,100		5,750			353			86	1,265			
P12	2.7	12,400	15,500		17,750			1,014			31	3,197			
P13	3.7	3,500	1,330		1,125			68			15	130			
WEST VIRGINIA[c]															
Northern West Virginia															
W1	2.9	16,500	4,090		10,054		664	50		145	67	2,240			
W1	3.0	9,300	6,940		9,560		680	220		380	70	2,940			
W2	4.9	5,000	150	-	3,800	780	146	3.6	22	415	9	260	-	-	0.2
W3	3.4	3,200	85	-	2,400	250	105	4.0	8	450	10	170	-	-	0.1
Southern West Virginia															
W4	5.2	640	11	-	310	14	28	1	10	30	3.4	45	-	-	0.1
W5	3.1	5,200	300	-	3,300	600	230	20	25	310	25	120	1.0	-	1.5
W6	4.5	710	15	-	400	6	45	1.8	11	36	1.8	40	-	-	0.3

TABLE 6 (continued)

Sample	pH	Conduc-tivity	Total Acidity	Alk.	SO_4	Na	Mg	Al	K	Ca	Mn	Fe	Ni	Cu	Zn
KENTUCKY[d]															
Eastern Kentucky															
K1	3.8	1,200	210	-	1,066	22	85	70	42	74	8.1	2.5	0.25	-	1.1
K2	5.0	840	30	-	690	30	56	10	16	60	3.1	2.0	-	-	0.5
K3	6.9	880	7	135	690	115	26	1.8	3.1	50	3.5	6.2	-	-	0.1
Western Kentucky															
K4	2.5	6,800	7,020		9,827	270	195	440	13	300	72	3,400	3.0	-	8
K5	2.4	4,200	2,380		3,629	150	90	244	0.7	200	26	630	0.45	-	2.9
INDIANA[e]															
IN1	3.2	1,480	150	-	850	40	75	5.6	6.2	150	11	25	-	-	-
IN2	2.8	2,500	800	-	1,711	30	100	52	-	200	25	100	-	-	-
IN2	2.6	2,400	760	-	1,700	18	100	50	3.4	160	24	160	0.40	-	1.7
IN3	2.4	6,400	6,500	-	9,512	200	285	340	3.0	350	120	2,600	1.6	0.16	7.2
IN3c	8.0	2,150	0	266	1,456	130	165	10	1.4	300	0.6	2.5	0.13	-	-
IN4	2.5	9,800	10,300		10,400		185			342	40	4,180			
IN4	2.2	15,000	16,400		15,200						36	5,500			
IN5	2.3	1,200	13,600		15,000						56	4,500			
IN6	2.5		7,277	-	14,282	42					12	2,320			
IN6a	7.9		-	125	564	20					0.03	0.5			
IN6b	2.9		5,660	-	10,544	256					10	2,233			
IN6p	2.3		8,667	-	16,103	4					11	2,147			

(continued)

TABLE 6 (continued)

Sample	pH	Conductivity	Total Acidity	SO_4	Total Fe	Fe^{++}	Total Solids
			ILLINOIS				
I1	3.6		640	1,200	55		8,570
I2	2.9		4,600	3,200	1,400		14,420
I3	3.3		6,100	2,800	50		16,830
I4	3.1		5,900	1,950	1,200		11,060
I5	2.8		8,700	3,550	4,600		13,860
I6	2.4		14,400	3,540	13,500		35,320
I7a high	8.8	1,990	190	5,760	89	53	
median	6.6	1,080	-20	550	2.9	0	
low	4.2	226	-550	80	0	0	
I7b high	3.4	19,150	21,400	23,550	5,930	5,370	
median	2.65	6,370	6,500	6,100	1,510	1,160	
low	2.05	875	500	625	115	89	
I8 high	3.54	24,100	25,700	28,600	7,820	7,560	
median	2.5	16,800	21,430	24,000	7,090	6,710	
low	2.1	9,400	9,300	4,530	3,360	2,520	

Source: Reference 8.

a. All values in milligrams per liter except conductivity (umhos) and pH (standard).

b. Acidity to pH 7.3 for samples P1 - P5b.

c. Acidity to pH 7.3 except for sample W1.

d. Acidity to pH 7.3.

e. Acidity to pH 7.3 for samples IN1 - IN3c.

f. Acidity by hot hydrogen peroxide method E, ASTM D-1067, for samples I7a - I8.

The most serious problem associated with the chemical composition of refuse is the presence of the pyritic group of minerals (commonly iron sulfide) in a form which oxidizes readily. In the presence of air and water the chemical reactions produce sulfuric acid. However, not all pyrite is readily oxidized. Caruccio[9] found that finer-grained pyrites (2 to 15 microns) oxidized rapidly in the presence of air but that coarser pyrites (greater than 50 microns) remained stable.

While acid drainage is accepted as the most serious chemical water pollution problem associated with refuse piles, other chemical pollutants are a dominant concern for specific mines. For example, in parts of southern Illinois there are sufficient alkaline salts in the refuse to neutralize acid production, but a high concentration of chloride(s) in the refuse is a cause of concern.

PROPERTIES OF FINE REFUSE

Fine refuse is generated in the preparation plant at various points, depending on the beneficiation method used. Fine refuse is a sandy, silty type of material which is commonly mixed with water conveyed hydraulically to settling basins. The physical properties of fine refuse, particularly its grain-size distribution and resulting in-place dry density, are significantly influenced by the natural sedimentation process in the settling basin, which tends to concentrate the larger, heavier particles near the discharge point and the finer, lighter particles farther away.

Essentially the same type of physical and chemical properties testing is used for fine refuse as for coarse refuse. But, although the identifying properties are the same, the two materials are entirely different in physical makeup.

Index Properties

Grain-Size Distribution--

The gradation results for 63 samples of fine coal refuse from eight sites in West Virginia are shown on Figure 8.[1] The results, presented in the form of a range of all samples tested, a range including 70% of all data, and the arithmetic average, indicate that an average of 45% of these materials pass the #200 sieve. The range in percent passing this sieve varies from approximately 18% to 98%, which reflects the influence of the point of discharge and the settling characteristics of the materials.

Plasticity--

The minus #40 fraction of the fine refuse materials is nonplastic. Several attempts were made to perform Atterberg limits tests on the fine refuse, and, although a liquid limit between 30% and 50% was achieved on some samples, it was not possible to roll threads to 0.32 cm (1/8 in.) diameter in order to determine the plastic limit; therefore, the material is classified as nonplastic.

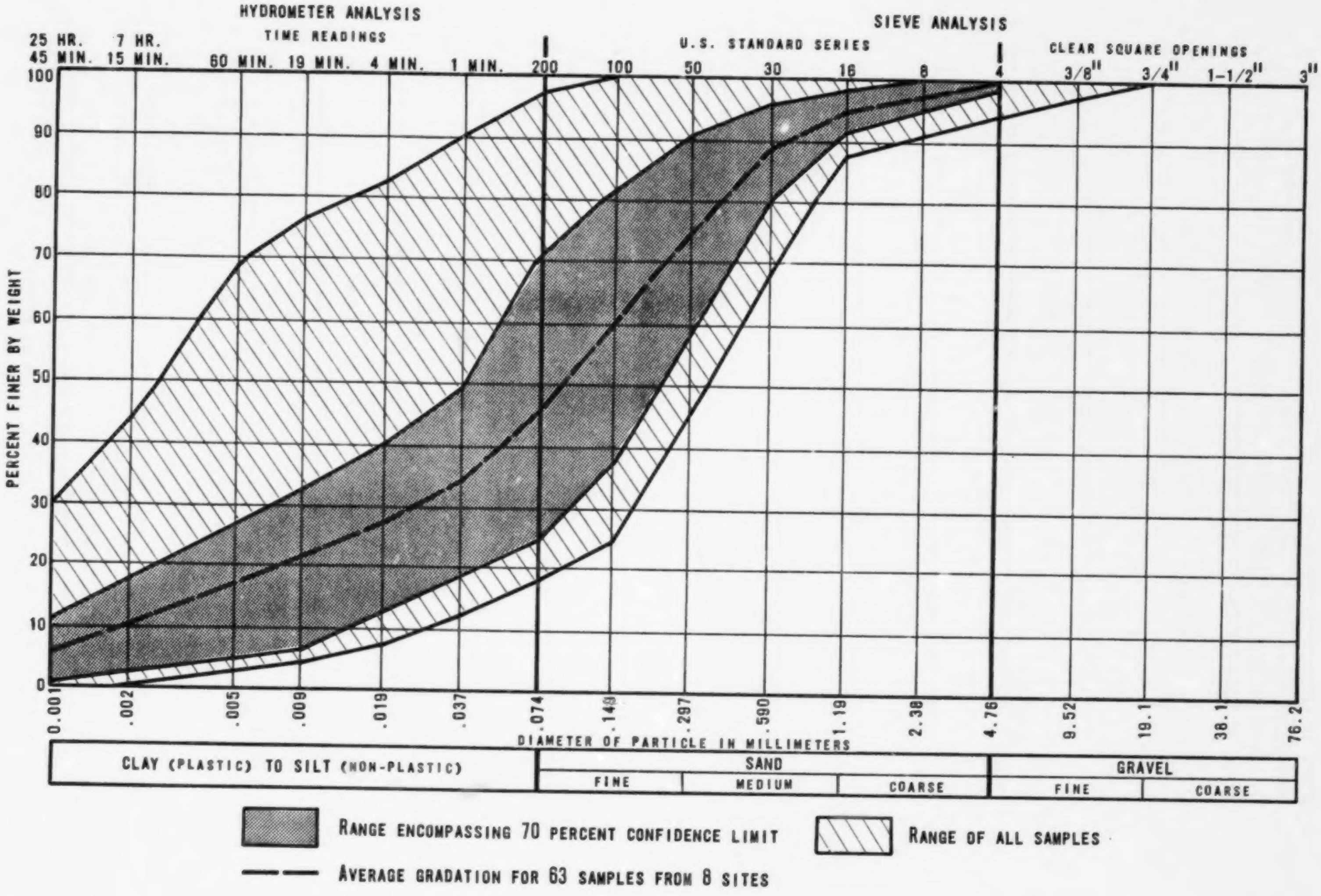


Figure 8. Gradation summary, fine coal refuse.

Specific Gravity--

Specific gravity values for the fine refuse range from about 1.3 to 2.2, depending on the percentage of coal in the material. Specific gravity results for 30 fine refuse samples are tabulated below.

No. of Samples	Specific Gravity Range
8	1.30 - 1.40
15	1.41 - 1.60
4	1.61 - 1.80
2	1.81 - 2.00
1	2.01 - 2.20
Average Specific Gravity	1.53

Source: Reference 1.

Engineering Properties

Natural Water Content and Dry Density--

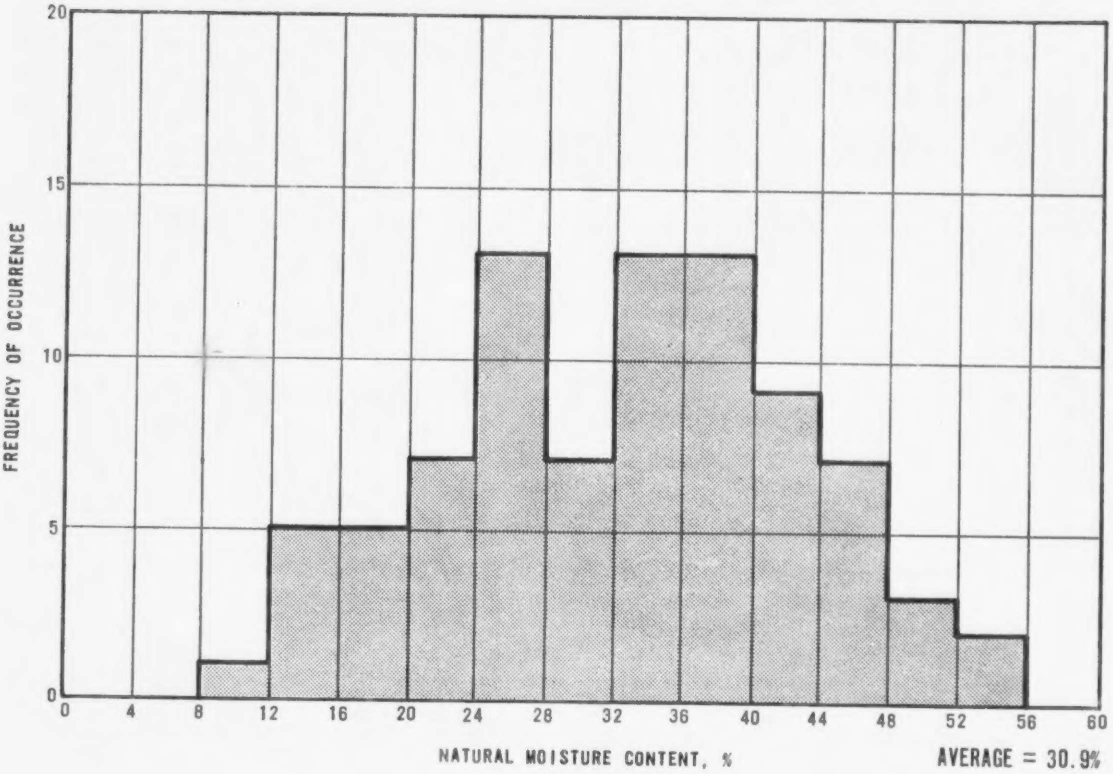
The natural water content and dry density of the fine refuse materials were determined from both field density and undisturbed tube samples. Results of the natural water content for 87 samples are shown on Figure 9, in the form of observed water content versus frequency of occurrence. A range in natural water content from 8% to 56% was observed, with an average value of 30.9%.

Seventy-eight field dry density values were determined for the fine refuse materials (see Figure 10). These values ranged from 705 to 1,346 kg/m^3 (44 to 84 lb/ft^3), with 85% of all the values ranging between 769 and 1,089 kg/m^3 (48 and 68 lb/ft^3). The arithmetic average dry density value was 884 kg/m^3 (55.2 lb/ft^3). Although these values are exceedingly low for the fine refuse materials, compared to an average dry density of 1,762 to 1,922 kg/m^3 (110 to 120 lb/ft^3) for typical soils, the void ratio of the fine refuse indicates a generally close packing of individual grains. An average void ratio (a comparison of the volume of voids with the volume of solids in a given sample) of 0.5 or less is not uncommon.

Compaction--

The moisture-density characteristics of the fine refuse materials were determined by testing 15 samples compacted in accordance with ASTM D1557-70, modified to 768 joules/m^3 (20,000 ft-lb/ft^3) compactive energy. The results indicate that a maximum dry density between 921 and 1,065 kg/m^3 (57.5 and 66.5 lb/ft^3) was achieved for a specific gravity between 1.3 and 1.4, and that a range of 1,185 to 1,297 kg/m^3 (74.0 to 81 lb/ft^3) was achieved for specific gravities between 1.41 and 1.70.

When the range of in-place dry densities previously referenced is compared with maximum laboratory densities, it is observed that the ponding methods being used to dispose of the fine refuse materials resulted in relative compactions of approximately 75% to 85%; however, the in-place moisture



NOTE: DATA FROM 87 SAMPLES FROM 8 SITES IN WEST VIRGINIA.

Figure 9. Natural moisture content, fine coal refuse.

contents were 10% to 20% higher than the optimum moisture contents. If fine-grained coal refuse is to be used as a construction material for water-retaining structures, the material could be compacted, by the use of mechanical compaction equipment. However, regardless of the density to which the material is compacted, it must be recognized that the low specific gravity and resulting in-place dry densities could lead to piping or instability problems if the fine-grained material is not properly ballasted, or confined, by heavier materials.

Permeability--

The permeability characteristics of the fine coal refuse materials were determined by thoroughly reviewing the disposal methods and laboratory test results. This evaluation indicated that a significant degree of anisotropy is developed in the fine-grained refuse materials because of their method of disposal. The fine-grained materials in the field are found to be highly lenticular, with stratifications varying from fractions of an inch to several inches

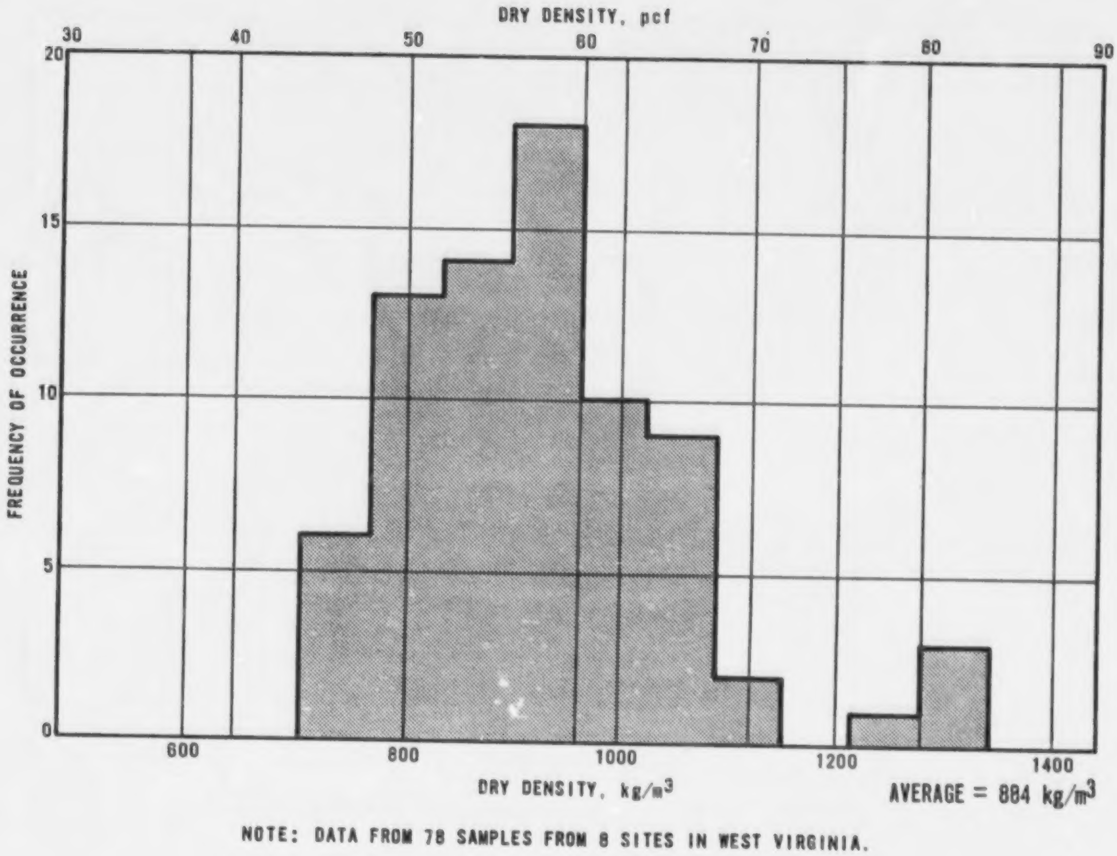


Figure 10. In-place dry density, fine coal refuse.

in thickness. The finest-grained silts usually constitute the thinner partings, and probably reflect variations in inflow of the slurry. These materials exhibit a coefficient of permeability of about 10^{-7} cm/sec, whereas the fine- to medium-grained silty sand which constitutes the coarser fraction of the fine-grained material has a maximum coefficient of permeability of about 3 x 10^{-4} cm/sec. The ratio of horizontal to vertical permeability for the fine refuse material ranged from 15:1 to 100:1, with an average value of approximately 25:1.

The National Coal Board of England study[3] indicates a range in the coefficient of permeability of 10^{-3} to 5 x 10^{-7} cm/sec in the horizontal direction and 10^{-6} to 7 x 10^{-8} cm/sec in the vertical direction.

The high degree of anisotropy of permeability values for the fine refuse materials is extremely important to recognize when considering the stability characteristics of refuse impoundments, especially if fine-grained materials form the foundation for an overlying coarse refuse embankment. The reason for the concern is that the relatively high ratio of horizontal to vertical permeability causes water to flow preferentially in a horizontal direction through these materials, thereby possibly transmitting high pore pressures beyond the toe of the embankment.

Compressibility--

The compressibility characteristics of the fine refuse materials were investigated utilizing triaxial test results. (Because of the extremely low density and nonplastic characteristics of these materials, it is very difficult to prepare samples for one-dimensional consolidation tests.) A range of volumetric compression of 2% to 4% was observed for the anisotropically consolidated samples, as compared with approximately 6% for the isotropically consolidated samples at 689 x 10^3 Pa (100 psi) maximum effective principal stress. The initial dry densities for the triaxial samples ranged from 833 to 1,025 kg/m^3 (52 to 64 pcf). These data indicate that the fine-grained materials are, in fact, less compressible than the coarse-grained materials discussed earlier. Again, it should be pointed out that the compressibility characteristics of the fine-grained materials are not unusually high; therefore, these materials can be safely used as construction materials if proper construction techniques and adequate protection against uplift and piping potential are incorporated in the design.

Shear Strength--

Shear strength parameters of the fine refuse materials were determined from laboratory triaxial tests performed on 32 samples, to obtain shear strength versus normal stress for both effective and total stress. These undisturbed tube samples were tested under ICU conditions.

The shear strength results indicate that the angle of internal friction, based on effective stresses, ranges from 37 to 40.5 degrees, with little or no cohesion indicated, and that the angle of internal friction based on total stresses is approximately 20 degrees, with a cohesion intercept from 20.7 to 68.9 x 10^3 Pa (3 to 10 psi). The shear strength results are remarkably consistent, considering the range in dry densities tested, and obviously reflect the angularity observed in the fine-grained materials. As stated earlier, the shear strength values for these materials also appear to be consistent with those for other construction materials.

Chemical Properties

Very little documentation is available on the chemical properties of fine coal refuse. However, Haynes and Klimstra have determined some chemical properties of such refuse from sites in Illinois.[10] Their results indicate that fine refuse generally has a low pH and a high exchangeable calcium ion capacity.

The main reason why there are so very few data on fine refuse chemical properties is that the major pollution concern with respect to slurry ponds is usually the carryover of suspended solids, rather than chemical pollution. It would be reasonable, however, to assume that the chemical properties of fine and coarse refuse from a given preparation plant would not differ significantly.

SECTION 4

PREPARATION PLANT PROCEDURES

The properties of coal refuse are significantly influenced by the procedures used in the preparation plant. The most important physical property of refuse, grain size, is strongly dependent on the coal preparation process. Minor changes in the grain-size characteristics of coarse refuse have a dramatic influence on its permeability, and the permeability of the emplaced refuse is the most important physical property in terms of water and air pollution potential. Although the grain-size distribution of fine refuse also affects water and air pollution potential, the effects are less pronounced than for coarse refuse.

REFUSE RECOVERY CIRCUITS

The recovery circuit of a preparation plant has four principal components: dry solids recovery, coarse refuse slurry concentration and solids disposal, fine refuse slurry concentration and slurry disposal, and dust collection and disposal. The dry solids recovery and disposal process is simple and straightforward. These solids are generated in the coarse coal circuit as reject material from the rotary breaker and as dewatered solids from the coarse refuse screen. They are conveyed directly to the refuse bin for transport to the solids disposal area.

The water and refuse slurry from the hydrocyclone module and the Deister table module in the intermediate-size and fine-size coal cleaning circuit is piped to a screen classifier. The classifier concentrates the larger solids, commonly the plus 28-mesh Tyler sieve size, and discharges them to a conveyor system for transport to the refuse bin. The moisture carried out of the classifier is collected via natural drainage during the conveying process and is piped to a static thickener.

The fine refuse, including the silt and clay particles generated throughout the coal-washing system, is collected as a slurry underflow from the screen classifier or from the froth flotation module. This slurry is usually piped directly to the static thickener, where it is concentrated with the aid of various flocculants and piped in concentrated form to the slurry pond. The clarified water overflow from the static thickener is returned to the plant water system. This is one of the circuits used in conventional preparation plants. In a more sophisticated plant, the thickened concentrate underflow from the static thickener is routed to a refuse recovery vacuum filter and the filtrate is conveyed to the refuse bin for later transport to the disposal site. Slurry disposal is thus eliminated.

A dust collection system in the preparation plant usually consists of a dust collector and a wet scrubber attached to a thermal drying module. The slurry generated from the wet scrubber is piped to the static thickener.

PROCESS QUANTITIES

Over the past years, the percentage of refuse generated per ton of coal produced in the eastern United States has increased dramatically, particularly with respect to coal obtained from underground mines. This increase is largely due to changes in mining methods, to the demand for cleaner coals, and to the development of more efficient coal cleaning processes.

Table 7 presents data on refuse production at the sites studied during this project. At all the sites, substantially greater tonnages of coarse refuse than of fine refuse are generated. The maximum reported reject percentages at these sites is approximately 30%, but there are other coal preparation plants that have as much as 50% to 60% reject material.

MATERIAL SIZING

The refuse particle sizes usually generated in various types of recovery circuits are described below:

Coarse Refuse from Rotary Breaker

The refuse generated by the rotary breaker generally has a gradation between 10 cm and 30 cm. This material is very coarse and highly permeable. The percentage of coal included in the material may be relatively high because layers of coal may adhere to the refuse particles. Because of these characteristics, refuse from the rotary breaker could in certain cases require special pollution control consideration.

Refuse from the rotary breaker is either handled separately from the coarse refuse generated in other circuits or it is mixed with the other refuse prior to loading the material for transport. If the rotary breaker refuse is handled and disposed of separately, special provisions at the disposal area may be required to isolate this potentially troublesome product from air and water, particularly if the refuse is acid producing. If, however, this refuse is mixed with the other coarse refuse prior to loading for transport, or if the product is further crushed to smaller sizes, special pollution control provisions usually are not required.

It should be noted that the amount of reject from the rotary breaker is usually small (1% to 2% of the total coarse reject) compared to the total reject produced by the plant. Thus proper disposal of the reject from the rotary breaker is not considered a major problem.

Coarse Refuse from Screening Circuit

The coarse refuse generated in the screening circuit is usually graded between the No. 28 Tyler sieve size and a top size of 10 cm to 15 cm. In some plants the bottom size separation has been lowered from the No. 28 to the

TABLE 7. REFUSE PRODUCTION AT STUDY SITE PLANTS

Site	Type of Mine	Clean Coal Production (metric tons/day)	Percent Reject	Ratio of Coarse to Fine Refuse	Processing Methods	Coarse - Fine Refuse Separation Size	Percent Solids Concentration in Slurry
A	Surface	9,070	19%	2.8:1	Jigs and heavy media	--	--
B	Underground	5,442[a]	15[b]	--	Froth flotation and heavy media	#100 Tyler	--
C	Underground	2,721	25	6:1	Heavy media, froth flotation	#28 Tyler	14%
D	Underground	4,308	25	2:1	Jigs	#10 Tyler	15
E	Underground	9,070[a]	17[b]	--	Froth flotation, heavy media	#100 Tyler	--
F	Underground	6,122 - 6,694	18 - 25	--	Jigs and heavy media	#28 Tyler	--
G	Underground	8,480	15	2:1	Froth flotation, heavy media	#28 Tyler	--
H	Underground	10,884 - 12,698	30	8:1	Heavy media, concentrating tables, froth flotation	#100 Tyler	35

---

a. Raw coal production.
b. Coarse reject only; data on fine reject not available.

No. 100 Tyler sieve. In other plants the bottom size separation has been increased to the No. 10 Tyler sieve. Materials within these ranges are classified as semipermeable.

A comparison of the gradation of coarse refuse samples from disposal areas with the gradation limits established in the preparation plants indicates that there is an increase in the percentage of fines generated between the plant and the disposal area. This increase is attributed to degradation due to handling, compaction, and weathering.

Preparation plant procedures determine, to a large degree, the gradation and therefore the permeability of the refuse. Efforts in the preparation plant to minimize pollution potential of coarse refuse can most effectly be directed toward increasing the percentage of fines (percent by dry weight passing the No. 200 sieve) in the coarse refuse to an optimum value on the order of 15%.

Fine Refuse

Fine refuse generated in the preparation plant is commonly a cohesionless, sandy silt with a low specific gravity. This material is usually pumped in slurry form to settling ponds for disposal. Some of the more sophisticated preparation plants dewater the fine refuse sufficiently that it can be handled by conventional haulage equipment and can be placed in the disposal facility in the same manner as coarse refuse.

The pollution potential of fine refuse in slurry ponds is primarily related to silt carryover from ponds with open-water circuits and to airborne particulates from exposed pond surfaces. Except for dewatering the fine refuse, there is little that can be done in the preparation plant to make fine refuse more environmentally acceptable in the pond. However, in special situations where there is insufficient settling area in the pond, a chemical flocculant can be added to the slurry to agglomerate the fine refuse particles and thus to increase the rate of particle settlement.

SUMMARY OF PRINCIPAL GUIDELINES FOR PREPARATION PLANT PROCEDURES

- The division between coarse and fine refuse in the preparation plant should be on the smallest screen opening practical.

- Pollution control efforts in the preparation plant can most effectively be directed toward increasing the percentage of fines in the coarse refuse generated.

SECTION 5

SITE SELECTION

Selecting a coal refuse disposal site involves consideration of a number of interrelated variables. Some of the more important of these are hazard potential (and/or embankment safety), environmental impact, land availability, and cost. Land availability and cost are self-explanatory considerations. Hazard potential involves detailed consideration of the stability of refuse piles and slurry ponds, and this aspect is regulated by MSHA. The principal environmental considerations include water quality, air quality, and land use. The principal site selection variables in terms of environmental factors are topography, hydrology, surface and subsurface conditions, and proximity of the site to developed areas.

In some situations the selection of a refuse disposal area is relatively straightforward. For example, in Indiana, state laws require that coarse refuse from surface mines be disposed of in the bottom of the mine pit and covered with the mine spoil. Perhaps the most difficult areas to evaluate are the mountainous regions of Appalachia, where the steep topography limits the choice of suitable disposal sites.

ENVIRONMENTAL CONSIDERATIONS

Water Quality

The principal environmental concern with regard to a coal refuse disposal facility is usually water quality. Water quality concerns are associated with chemical degradation (such as acid drainage) and suspended solids. The most critical technical consideration in attempting to control water pollution at a refuse pile or slurry pond site is isolation of the site from surrounding surface and ground waters. Sites that have significant amounts of through drainage are less desirable than sites that have only minimal drainage. Likewise, a site where there is underground spring activity is less desirable than a site which has no spring activity.

Another very important consideration in site selection is the location of the refuse pile relative to the slurry pond. If at all possible, the refuse pile should be so sited that drainage from the surface of pile is directed into the pond. The pond then also functions as a sedimentation basin for any eroded sediment from the pile. In many situations, the slurry pond waters are alkaline and may effectively neutralize limited amounts of acid drainage from the pile.

Other site selection factors related to water quality include the presence of permeable substrata, which could lead to groundwater degradation, and the presence of shallow, underground mine workings, limestone solution caverns, landslides, or unstable ground, which could threaten the integrity of the refuse pile or slurry pond. Also, water pollution is usually more easily controlled on sites which have a gentle topography as compared to sites which are steep.

Air Quality

The principal air pollution concern associated with modern refuse piles is dust. (Burning refuse piles, which release various gases to the atmosphere, are largely restricted to older deposits that contain significant amounts of combustible materials and that were constructed by end dumping off steep slopes.) As in any construction activity, some dust and machinery noise are always associated with refuse pile construction. To minimize the adverse effects of dust and noise, sites should be remote or isolated from public areas, as far as possible. Specifically, sites where the prevailing winds would travel over refuse piles in the direction of nearby housing areas should be avoided.

Other factors to be considered are the length and location of haul roads between the disposal site and the preparation plant. Long haul roads through public areas are, of course, less desirable than short haul roads through isolated areas.

Another consideration in air pollution control is the method of disposal of trees, shrubs, and similar materials that are cleared from a refuse area. Often the dried debris from such clearing operations is burned. If a site is heavily wooded, air pollutants can be created by such burning operations.

Land Use and Reclamation

Land use and reclamation are very important factors which should be carefully evaluated in selecting a site. The long-term environmental effects of the completed refuse disposal facility are a vital part of the pollution control effort. In some cases it is possible to develop a finished refuse area so that the land's ultimate use has greater public or private value than was the case prior to refuse placement. For example, filling and reclamation of steep valleys in Appalachia can create flat land, which is at a premium in many localities and which can be used for parks, recreation areas, etc. Foresight, proper planning, and a conscientious effort can result in a refuse area which is an economic asset to the mine owner rather than a liability, as has so often been the case in the past.

From a pollution control viewpoint, choosing a refuse disposal site which minimizes the surface area for the required ultimate storage volume is very important. Concentrating the refuse in a small area not only optimizes land use but also reduces the water pollution potential.

COAL REFUSE DEPOSIT CLASSIFICATION SYSTEM

Given a particular disposal site, there are several facility configurations that might be utilized. The configuration with respect to site topography can dramatically influence the choice of pollution control methods. Land forms usually control the configuration of a coal refuse deposit, and particularly of the height and type of embankment. In the steep, mountainous terrain of Appalachia, cross-valley dumps and impoundments are most common and, because of the presence of narrow stream valleys or hollows, embankments tend to be relatively high. In contrast, in the flatter terrain of the Midwest disposal sites often cover larger areas and embankments are lower. The higher embankments and larger refuse piles usually (but not always) present greater potential air and water pollution problems.

System Development

A coal refuse classification system was developed by W. A. Wahler & Associates[1] to classify the numerous types of refuse piles and slurry ponds found in the coal fields of the eastern part of the United States. The following definitions were established:

Dump: A permanent or long-term accumulation of coal mine or coal processing refuse on or in earth; not capable of impounding fluid.

Impoundment: A depression, an excavation, a permanent or long-term accumulation of coal mine or coal processing refuse, or other facility on or in the earth; capable of impounding fluid.

Except when a disposal facility is constructed specifically for the purpose of impounding liquids, its configuration usually depends on the equipment used to move the refuse and on the topography of the disposal site. Of these two factors, the topography most affects the general configuration. Five classes of refuse pile configurations have been established:

I. Valley-fill
II. Cross-valley
III. Side-hill
IV. Ridge
V. Waste heap

In addition, four slurry pond classifications have been selected:

VII. Cross-valley
VIII. Side-hill
IX. Diked pond
X. Incised pond

These classes are illustrated on Figures 11 and 12.

By dividing complex disposal sites into simple forms, the classification system adequately defines the type (or types) of sites. However, using these simple forms for extremely complex sites may make the data collection task

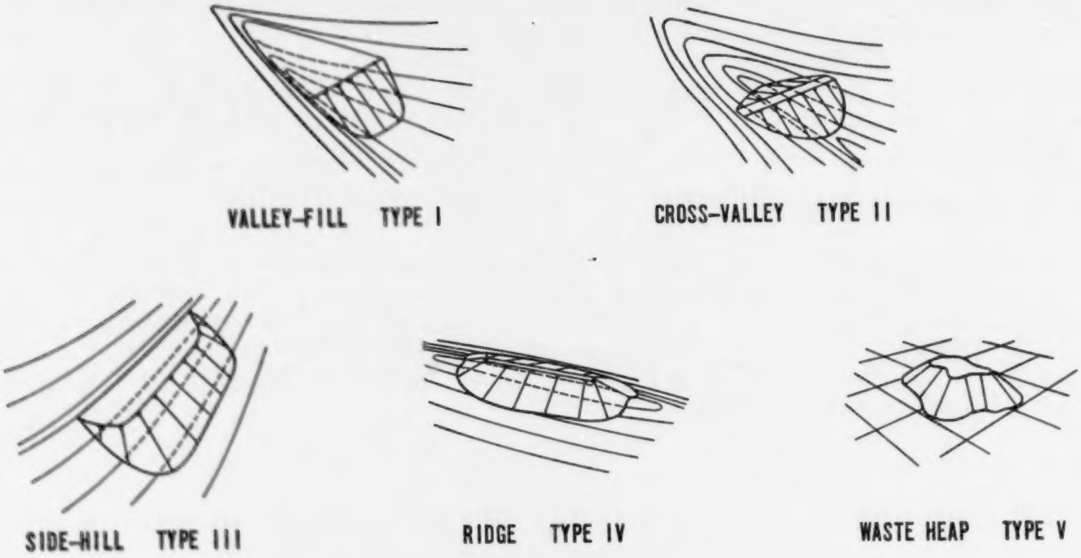

VALLEY-FILL TYPE I
CROSS-VALLEY TYPE II
SIDE-HILL TYPE III
RIDGE TYPE IV
WASTE HEAP TYPE V

Figure 11. Simple refuse pile forms.

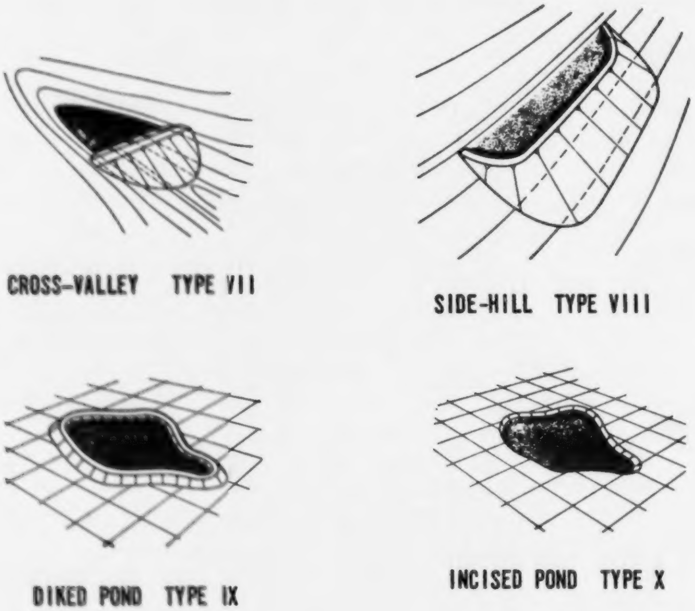

CROSS-VALLEY TYPE VII
SIDE-HILL TYPE VIII
DIKED POND TYPE IX
INCISED POND TYPE X

Figure 12. Simple slurry pond forms.

more difficult. When this appears to be the case, the configurations call for special definition (such as plan, sketches, and diagrams) and are designated as Type VI for refuse piles and Type XI for slurry ponds.

Each type of site described above has some unique characteristic. The nine simple types (I through V and VII through X) are discussed in the following paragraphs.

Type I: Valley-Fill Refuse Pile

A valley-fill pile completely fills a valley, has an almost flat, horizontal or sloping upper surface, and cannot impound water. The pile is usually extended downslope by placement of refuse on the "downstream" face of the pile; however, some have started as cross-valley fills that are later filled in on the "upstream" side. This type of coarse refuse pile is common in hilly or mountainous terrain.

Type II: Cross-Valley Pile

A cross-valley pile bridges a valley but does not completely fill it. The crest of the pile may be reasonably horizontal or it may slope steeply. So that it will not constitute an impoundment, it must be drained by natural or man-made means. This type of facility is common in hilly and mountainous terrain. As discussed later (under Type VII: Cross-Valley Slurry Pond), one common practice is to use a cross-valley refuse pile as a dam or dike to retain a fine-refuse slurry pond. Other practices are to construct a cross-valley pile with culverts running under it to carry stream flows, or to make the refuse so pervious that water will flow through the voids.

Type III: Side-Hill Pile

A side-hill pile is constructed along one side of a valley. If the pile becomes large enough to cross the low point (or stream) in the valley, it can in part or in total be classified as a cross-valley pile. Side-hill piles are well suited to gently sloping sites where the ground conditions are stable.

Type IV: Ridge Pile

A ridge pile straddles a ridgeline or the nose of a ridge. This type of refuse disposal facility, although sometimes used in gentle or hilly terrain where valley slopes are stable, is not in common use.

Type V: Waste Heap

Waste heaps are constructed on relatively flat surfaces and have sloping surfaces around all sides. This type of coarse refuse pile is very common in the Midwest, where flatlands predominate.

Type VII: Cross-Valley Slurry Pond

A cross-valley pond often has a retention embankment that resembles a normal earth dam. The embankment crosses the low point of the valley and has a crest above the natural drainage elevation. This type of impoundment facility is in widespread use wherever the topography permits, because this is usually the most economical method of creating an adequate slurry pond. The embankment may or may not be partially or fully composed of coarse mine refuse.

Type VIII: Side-Hill Pond

A side-hill slurry pond is usually a three-sided dike system located on gently sloping ground. The fourth side is the valley slope. As does the side-hill refuse pile (Type III), the side-hill pond requires gentle and stable valley side slopes. This type of construction is commonly found in wide valleys where slopes are not steep.

Type IX: Diked Pond

A diked pond has a four-sided embankment which completely encircles the impoundment area. There is no inflowing drainage area outside the crest of the embankment. Closed dike systems are common in the Midwestern flatlands. For reasons of economics, the embankments are usually low in height.

Type X: Incised Pond

An incised pond is formed by an excavation and lies completely below the surrounding ground surface. This type of disposal facility is commonly used by surface mines, where the last cut in the mining operation can be developed as the slurry pond.

POLLUTION CONTROL

Each type of refuse pile or slurry pond has particular advantages, disadvantages, and/or requirements which are related to pollution control. Some of the more important considerations are summarized below.

Type I: Valley-Fill Pile

A valley-fill pile can best be developed by starting at the head of the valley and filling in the downstream direction. Many valleys in Appalachia are deep and relatively narrow. By filling in such a valley, it is possible to store large amounts of refuse within a relatively small area. Limiting the surface area of the pile reduces the total amount of exposed refuse and therefore reduces the water pollution potential. Also, filling in a valley and reclaiming the surface eventually provides valuable flat or gently sloping land.

Natural springs or water seeps along valley sides are common in certain locales. Valley-fill piles in such areas must therefore have underdrain systems. Depending on construction methods, a perimeter ditch around the sides of the valley may be required to divert drainage away from the pile.

Type II: Cross-Valley Pile

A cross-valley pile, in contrast to a cross-valley pond, is not intended to impound water. Therefore, rather large culverts in valley bottoms are generally required, to pass flood waters. This type of arrangement is normally the least desirable of all the refuse pile types, because water diversion and long-term reclamation require maintaining the underlying culverts.

If the refuse material particles are of such a size that stream flows pass freely through large, open voids, this is considered poor pollution control management, because the water could pick up harmful acidity or suspended solids. The potential for spontaneous combustion is also increased, because air can enter the open voids in the refuse.

Type III: Side-Hill Pile

Side-Hill piles are well suited to gently sloping terrain where ground conditions are stable. For such a facility, however, diversion of uphill waters is almost always required. With this type of refuse pile the main valley drainageway is always left open. Therefore, compared to valley-fill or cross-valley refuse piles, diversion of uphill surface waters around a side-hill refuse pile can normally be accomplished in a more reliable fashion, thus reducing the water pollution potential. Care must be taken to limit the lateral extent of the side-hill refuse pile in the vicinity of the main drainageway in the valley bottom. If the refuse pile unduly restricts the flow capacity of the main valley stream, floods could erode out substantial amounts of the pile, causing serious downstream water pollution concerns, a poor aesthetic appearance, and a potential for major stability problems which, if not rectified, could lead to temporary damming of the drainageway and subsequent downstream flooding.

Type IV: Ridge Pile

A ridge pile requires no special diversion works, because there is no uphill drainage basin. However, special erosion-resistant drainage ditches are needed on the side (or sides) of the pile, in order to drain its upper surface.

A ridge pile should be sited where there are stable valley slopes capable of withstanding the additional stress imposed by refuse. The top of the ridge should be relatively wide and the valley slopes should be relatively flat, so that significant amounts of refuse can be stored satisfactorily.

Because this type of refuse pile normally is highly visible and exposed, it should be avoided, if possible.

Type V: Waste Heap

Where the topography permits, this type of pile is considered to be the most favorable with respect to safety and pollution control. The shape of this type of pile is quite flexible, which permits optimum utilization of the site. Surface drainage usually can be easily diverted around the pile through open ditches.

A waste heap can be moderately to highly visible, and slope reclamation requirements are usually more extensive than for other types of piles.

A waste heap is best developed using cellular construction procedures.

Type VII: Cross-Valley Slurry Pond

This type of disposal facility is most advantageous at sites where the drainage area is small and where the valley slopes are gentle. It is least advantageous where there are steep valley slopes and large upstream drainage basins. Cross-valley slurry ponds in narrow valleys with large upstream drainage areas are often major water pollution sources. Because reliable diversion of upstream waters is difficult to achieve, heavy flood-water runoff can literally flush out fine refuse previously deposited in the slurry pond, discharging the material to downstream receiving streams and thus creating sedimentation and chemical water pollution problems. Cross-valley slurry ponds with the adverse characteristics mentioned above should therefore be avoided.

Cross-valley ponds with small drainage basins above the pond often may be designed to hold flood waters, thus eliminating or reducing the need for downstream releases. In such a case the pond's water circuit may be closed and clarified water may be recycled to the preparation plant for reuse. This dramatically eliminates or reduces the pollution potential. Also, with this type of slurry pond it is often possible to develop large fine-refuse storage capacity and settling areas at a comparatively low cost.

Type VIII: Side-Hill Pond

The pollution control considerations for side-hill slurry ponds are the same as those mentioned for side-hill refuse piles.

Type IX: Diked Pond

Diked ponds are considered to be the best form of slurry pond from a water pollution standpoint, because they eliminate the problem of an upstream drainage basin discharging waters into the pond. Essentially flat or very gentle sloping terrain is required for a diked pond.

Diked pond embankments are normally not as high as other types of slurry pond embankments. Also, diked ponds are readily amenable to being divided into compartments for better management of distribution of settled solids, decanting of clarified water, and/or reclamation activities.

Type X: Incised Pond

The most significant disadvantage of the incised, or below-grade, pond is the potential for ground-water degradation. The excavation for the pond (or spoil banks if the pond is located in an abandoned surface mine) may expose more permeable subsurface conditions than exist on the natural ground surface. If pond waters are contaminated, or if seepage through spoil areas picks up excessive amounts of dissolved salts, ground-water degradation problems could arise. Pond liners could be used to seal off permeable zones; however, liners are costly and are subject to damage if the solids are to be reclaimed later.

SUMMARY OF PRINCIPAL SITE SELECTION GUIDELINES

- It is important to locate refuse piles and slurry ponds in areas where the refuse can be isolated from ground and surface waters.

- Whenever feasible, a refuse pile should be sited so that drainage from the pile is directed into the slurry pond (if any).

- Sites with shallow underground mine workings, limestone caverns, or highly permeable subsurface conditions should be avoided.

- Waste heap piles and diked slurry ponds are usually the most advantageous types of disposal arrangements in terms of pollution control.

- Cross-valley slurry pond sites with steep valley slopes and large upstream drainage basins should be avoided.

SECTION 6

CONVEYANCE SYSTEMS

Coarse refuse can be transported from the preparation plant to the disposal area using trucks, scrapers, rail, conveyor belts, or aerial tramways, alone or in various combinations. Each system (or combination) has different advantages and disadvantages from the standpoint of pollution control. The conveyance of fine refuse from preparation plants to slurry ponds is accomplished using pumps and one or more pipelines. Properly designed and constructed, the pipeline is an excellent transport vehicle with respect to pollution control.

COARSE REFUSE CONVEYANCE SYSTEMS

Refuse spillage between the preparation plant and disposal area creates two pollution control problems:

1. Erosion and Siltation - spilled refuse is normally loose and highly susceptible to erosion. The eroded material may be transported to and deposited in streambeds where it can inhibit aquatic life and vegetative growth.

2. Acid Drainage and Heavy Metals - waters falling on, or passing through, acid-producing refuse will pick up oxidized sulfur and soluble heavy metals which could significantly pollute downstream waters.

Each conveyance system has characteristics which require provisions to minimize potential pollution.

Wheeled Vehicles (Trucks and Scrapers)

To minimize spillage from wheeled vehicles, they should not be overfilled, and the gates on the vehicles should be carefully maintained to ensure tight closure. In addition, the haul roads between the preparation plant and the disposal area should not be constructed of acid-producing refuse unless the roads are surfaced with a relatively impermeable wearing surface or drainage from the roads is controlled within acceptable water quality limitations.

Rail Transport

Railroads are seldom used for hauling coarse refuse; when they are, the spillage control precautions necessary for truck and scrapers also apply to rail transport. However, railroad track beds are not usually constructed with coarse refuse as ballast.

Conveyor Belts

The use of a conveyor belt system for refuse transport involves the removal of refuse via the belt to a storage location adjacent to the disposal area. From there the refuse is distributed by truck, scraper, or bulldozer units. An important feature of refuse disposal conveyor belts is a belt reversal mechanism, so that the belt can be mechanically rotated at the discharge point to prevent the wet, refuse-carrying side from contacting the return idlers. This prevents the deposition of carry-back material along the beltway and the buildup of wet, sticky material on the return idlers, thus minimizing adverse effects on belt alignment.

Aerial Tramways

Aerial tramways are sometimes used in steep terrain where slopes exceed allowable grades for wheeled vehicles or conveyor systems. Prior to the 1972 Buffalo Creek disaster, aerial tramway systems were commonly used to gravity-dump refuse across a valley. In many cases, this led to undesirable materials segregation, slope instability, refuse pile fires, and water pollution. Modern practice requires aerial tramways to dump the refuse adjacent to the disposal area. From this point it is moved by bulldozers or loaded into trucks or scrapers and placed in controlled layers.

Some of the older tramway systems had severe spillage problems along the cableways, particularly during freezing weather. Wet refuse would freeze or stick in the tramcars and fail to dump at the proper unloading point. Tramcars would often lose the material somewhere along the tramway alignment while returning in the upside-down position to the preparation plant. Cleaning up spillage along the route of an aerial tramway is a rather difficult and awkward task, because the terrain that aerial tramways traverse is usually steep. Aerial tramways should incorporate provisions for preventing unintentional dumping of refuse along the tramway route.

SLURRY TRANSPORT SYSTEMS

For pollution control, a slurry pipeline, which is an enclosed system, is an excellent means of conveying fine refuse from the preparation plant to the disposal area. Refuse spillage is limited to potential leaks between pipe joints or to accidental breaks. Occurrences of this nature are relatively rare and normally prompt immediate remedial action.

Leaks in pipelines sometimes occur where the lines go under roadways or where shifting ground disturbs the original alignment. These problems can be minimized in several ways, for example by installing structural sleeves between the roadbed and pipe. Pipeline alignments that cross unstable ground should be avoided, unless problem areas have been stabilized.

Slurry pipelines are constructed of a variety of materials including steel, concrete/asbestos/cement, plastic, and other synthetic resins. The pipelines may or may not be buried. Buried lines are less susceptible to damage from surface activities and normally are not exposed to the extreme temperature variations that cause expansion and contraction of surface pipelines. Surface pipelines, on the other hand, are easily inspected and can be readily repaired in the event leaks do occur. Slurry pipelines normally have a drain valve and a sump at each low point along the alignment. These valves and sumps are required to avoid plugging of the line in the event of a pump shutdown when the line is full of slurry. For proper pollution control management, the sumps should be adequately sized to accommodate the drained-off slurry and the sumps should be cleaned and solids properly disposed of after each use. Prior to any planned pump shutdown, the pipeline should, of course, be flushed with clear water to avoid plugging the line.

SUMMARY OF PRINCIPAL CONVEYANCE SYSTEM GUIDELINES

- Acid-producing refuse should not be used as a construction material for haul roads.

- Conveyor belts should be equipped with a belt reversal mechanism on the return circuit.

- Aerial tramway systems should include provisions to preclude spillage of refuse along tramway routes.

- Structural sleeves should be installed in pipeline systems where such lines pass under roadbeds.

- Pipeline alignments should not pass through unstable ground areas unless provisions have been made to stabilize problem areas.

SECTION 7

GUIDELINES FOR REFUSE PILE CONSTRUCTION AND OPERATION

Pollution control during coal refuse pile construction and operation involves the following principal considerations: site preparation and development; drainage and erosion control; refuse haulage, placement, and compaction; and dust control. The construction and operation of a coal refuse pile are similar to these activities for other major earthwork construction projects such as dams, roads, and structural fills. Many construction and engineering techniques used in construction work can be utilized for coal refuse disposal, if proper recognition is given to the unique character of refuse material itself and to the logistics associated with its production and transport. For example, in a major earthwork project some control is normally exercised over the type of materials placed in a fill, but the coal refuse disposal operator has little control over the type, quantity, or quality of reject material. Also, coal preparation plants operate under all weather conditions, and often during both daylight and dark hours. The refuse disposal operations must be able to adapt to the changing conditions without hampering preparation plant procedures. Refuse disposal requires handling a fairly steady stream of reject material on a relatively continuous basis, under varying weather conditions, over the life of the mine or plant.

SITE PREPARATION

Site preparation for refuse piles involves:

- Clearing, grubbing, stripping, and disposal of trees and heavy brush.
- Installation of a subdrain system (if required).
- Diversion of natural runoff water around the refuse site.
- Provision of a siltation basin downslope of the refuse pile (if required).

Clearing, Grubbing, and Stripping

Trees and heavy brush must be cleared in order to provide suitable access to the site and to remove organic material which could later decompose and cause environmental or structural problems. Grubbing of large, closely spaced tree stumps is normally required to prevent tire damage to the haulage equipment. Stripping of topsoil from under the pile area is done to establish a more stable foundation for the refuse pile and to provide a source of material for future reclamation activities.

The principal pollution concern with respect to clearing and grubbing is disposal of the debris. Trees of commercial value can, of course, be salvaged and sold. However, many disposal sites contain large amounts of trees and brush which have little or no commercial value. Options for disposal of this debris generally include chipping, burial, burning, and stockpiling.

Trees, tree limbs, and heavy brush can be reduced to wood chips using portable mechanical devices. The wood chips are hauled from the site and sold to chemical and industrial plants. This option represents the best environmental alternative for disposal of debris from heavily wooded sites that are within economic haul distances from wood chip users.

Cleared materials are sometimes buried, if the terrain is suitable and if the quantity of material is not too great. Cleared debris must not be buried in or under the refuse pile, because this would jeopardize the structural integrity and permeability characteristics of the pile. Instead, burial must be done outside the limits of the pile and in conformance with sanitary landfill regulations.

Burning of stacked or piled trees and brush, a traditional means of disposal, has come under increasing criticism and regulation for obvious safety and environmental reasons. If burning is permitted, only small fires should be used, and only under controlled conditions. Ashes should be quenched and properly buried or covered outside the refuse disposal pile. In some cases, the use of an air curtain jet may be desirable to increase the temperature of the burning material and thus reduce the air pollution potential.

In stockpiling cleared debris, large bulldozers are usually employed to push the material to the edge of the work area, where it is allowed to remain. Often the debris is simply left aboveground to decay. After a few years, the trees and brush dry out and can then constitute a substantial fire hazard. For this reason, stockpile materials from clearing operations should be covered with earth as specified in sanitary landfill regulations.

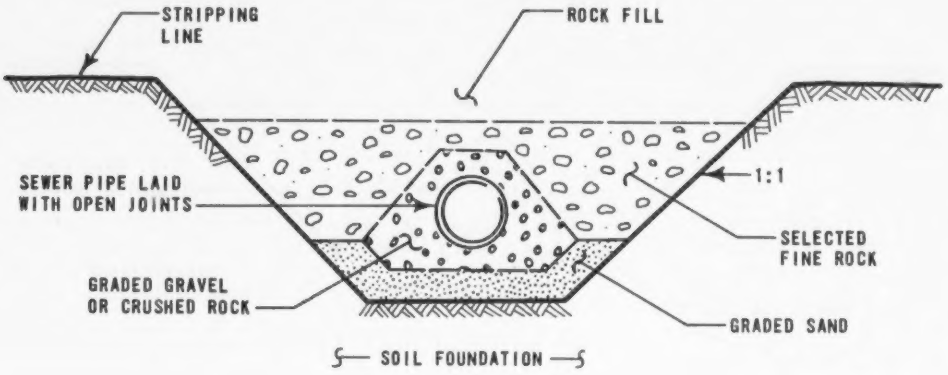
It is considered good practice to limit clearing and grubbing operations to immediate work areas, instead of clearing an entire refuse disposal area at the start of operations. This is to avoid unnecessary erosion and siltation problems. Also, in many parts of Appalachia the hillsides are unstable, and clearing the natural ground cover tends to increase the amount of water percolation into the soil, which in turn could lead to landsliding.

Stripping, or topsoil removal, is done to provide a firm foundation for the refuse pile and to develop a source of material for future site reclamation activities. This may reduce or eliminate the need for opening additional borrow areas for reclamation soils. However, some latitude is required when the refuse pile is located on steep terrain and it is not practical to stockpile and rehandle the topsoil.

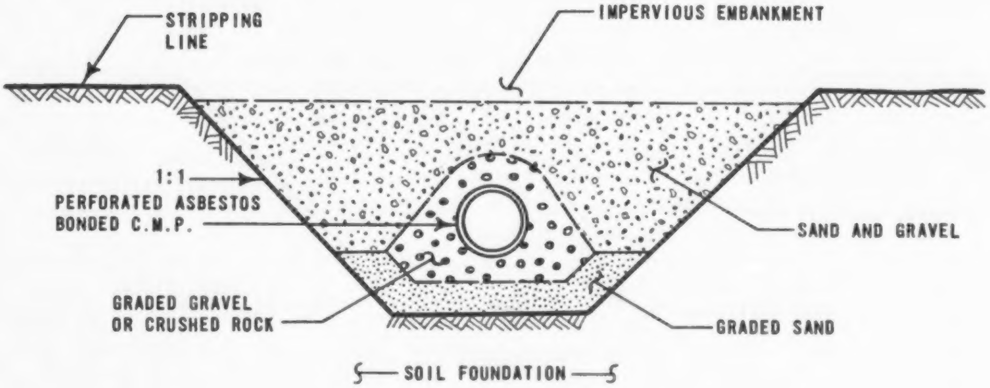
Installation of Subdrains

The purpose of a subdrain system is to drain away subsurface waters before they can reach the base of the refuse pile. Subdrains are required wherever springs or water seeps occur under a proposed pile. Subdrains are necessary for embankment stability and water pollution control reasons. By reducing the water in the pile's foundation, they also facilitate the initial placement of refuse. Subdrains are commonly required in the hilly terrain of Appalachia but are seldom needed at the flatter sites found in the Midwest.

As shown on Figure 13, subdrains normally consist of one or more layers of granular material surrounding a pipe. The gradation of this material is very important in terms of satisfactory performance of the system, and improper design and/or construction techniques have led to numerous problems in the past. The interested reader should refer to Reference 2 for a discussion of and recommendations for appropriate subdrain designs.


STRIPPING LINE
ROCK FILL
SEWER PIPE LAID WITH OPEN JOINTS
1:1
SELECTED FINE ROCK
GRADED GRAVEL OR CRUSHED ROCK
GRADED SAND
SOIL FOUNDATION

a. OPEN JOINT PIPE


STRIPPING LINE
IMPERVIOUS EMBANKMENT
1:1
PERFORATED ASBESTOS BONDED C.M.P.
SAND AND GRAVEL
GRADED GRAVEL OR CRUSHED ROCK
GRADED SAND
SOIL FOUNDATION

b. PERFORATED PIPE

Figure 13. Example of subdrain.

It is often hard to locate all the springs or water seeps in a proposed disposal site until the site has been cleared. Therefore, subdrain layout is usually not undertaken until construction activities expose spring and seep locations.

If the overlying refuse is acid-producing, the permeable portion of a subdrain system should be covered with at least 60 cm (about 2 feet) of clay soil or other suitable low-permeability material. This is to prevent contamination of the collected spring waters by waters which may be seeping through the refuse pile.

Diversion of Natural Runoff

Diversion of runoff waters around a refuse pile is an essential pollution control requirement. Normally, diversion ditches are excavated around the perimeter of the site, to control surface drainage. In flat or gentle terrain, construction of such ditches is relatively straightforward, but in steep, heavily wooded terrain, where valley-fill disposal operations are common, ditch construction is more difficult. The design and construction of diversion ditches is further complicated in many parts of Appalachia by the existence of active landslides along valley slopes, because drainage ditches that run parallel to the ground contours increase slope instability. However, ridgetop disposal sites, or sites where the drainage is consistently away from the refuse pile, do not require diversion facilities.

Diversion ditches must be protected with riprap, drop structures, or other suitable materials or devices in cases where the water velocity would cause erosion of the natural materials.

Siltation Basins

Siltation and debris basins are often constructed downslope from refuse piles as a means of minimizing the discharge of waters containing suspended solids. In most cases, such basins also serve other purposes. For example, five of the nine study sites have siltation basins incorporated in their layouts, and these basins may have one or more functions, including serving as a recirculating pond, a receiving basin for slurry pond waters, a makeup water and siltation collection basin, and/or an emergency slurry pond.

The most common function of a siltation basin is to act as a slurry pond for fine refuse. Directing surface drainage from a coal refuse pile into a proper slurry pond is an excellent means of pollution control. Such an arrangement can substantially promote the removal of suspended solids and the partial or complete neutralization of acid drainage.

In the steep, narrow valleys of Appalachia it is very difficult to provide permanent siltation basins, because major embankments and associated spillway structures would be needed in order to develop adequate settling areas and to prevent overtopping. In these circumstances, special arrangements would be required, which might include:

- Construction of a major downstream slurry pond and appropriate spillway.

- Development of small, temporary siltation basins immediately below the toe of the refuse pile, with appropriate diversions around the basin. These basins would have to be abandoned periodically and new ones would have to be constructed downstream as the refuse pile expanded in the downslope direction.

- Installation of special retention structures (for example sheet piles) that would permit overtopping without breaching.

SITE DEVELOPMENT

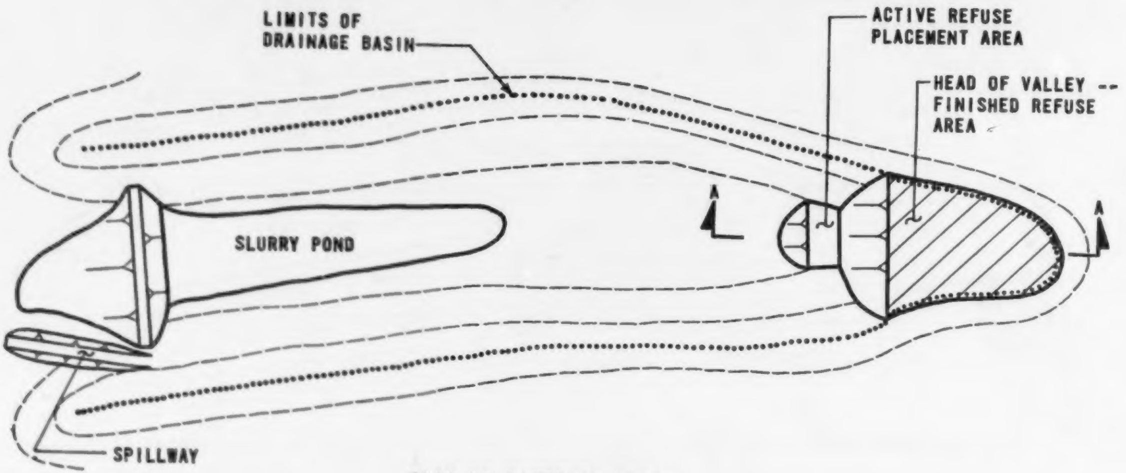
Prior to starting disposal operations, it is essential to have a site development plan that includes pollution control measures. Appropriate starting and ending points must be established, as well as detailed plans for drainage and reclamation works. The plan should include the sequential construction operations associated with full development of the site. The scope and detail required for site development and pollution control planning will, of course, vary according to the nature of the individual site and the properties of the refuse to be disposed of.

Site development planning is greatly influenced by the type of refuse pile (valley-fill, side-hill, waste-heap, etc.) selected. For each type there are preferred construction schemes that will aid in pollution control.

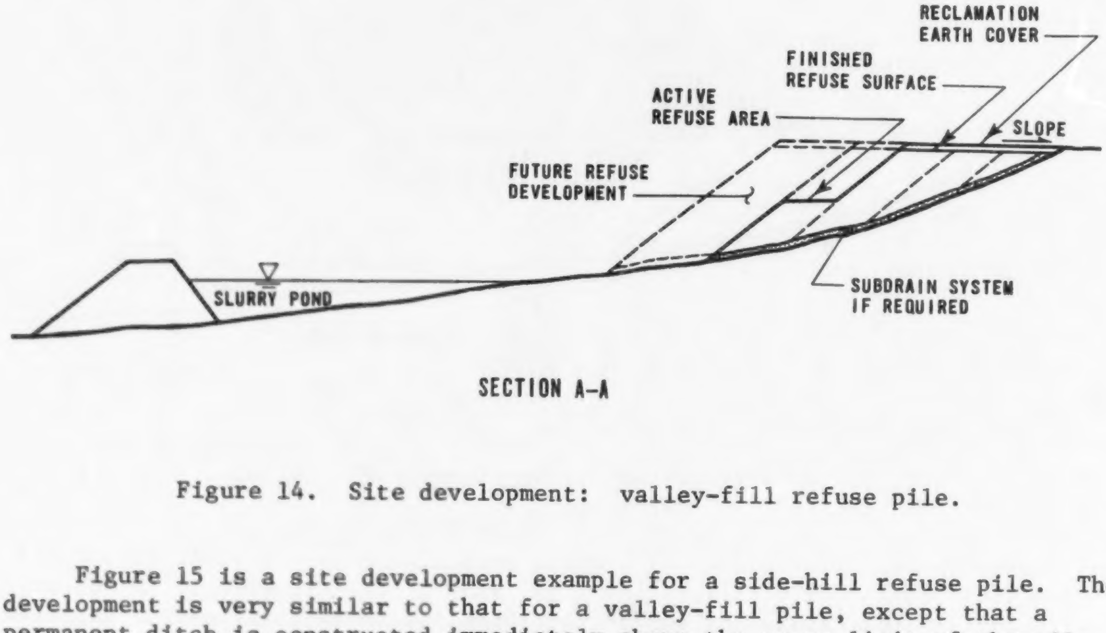
Figure 14 is a plan and section of a valley-fill refuse pile with a downstream slurry pond. For pollution control, it is important to start filling at the head of the valley and to develop the site in the downslope direction. Ideally, the pile should be brought up to a finished surface elevation that is slightly above the elevation of the drainage basin, so that drainage from the finished surface can be readily directed into adjacent drainage basins. This avoids the need to construct and maintain ditches along the side of the valley, and pollution risks associated with ditch failures during heavy rains are thus eliminated.

The refuse area in Figure 14 is constructed in benches (or strips) perpendicular to the valley line. After each bench reaches its ultimate level, the finished surface is sloped to drain away from the working slope and is covered with earth as required for reclamation procedures.

The arrangement shown in Figure 14 minimizes the exposed refuse surface area, provides a reliable system for diverting surface and subsurface waters, and allows reclamation activities to take place during the operating life of the site. The downstream slurry impoundment also serves as a sedimentation basin for any coarse refuse eroded off the slopes of the active refuse pile.


LIMITS OF
DRAINAGE BASIN
ACTIVE REFUSE
PLACEMENT AREA
HEAD OF VALLEY --
FINISHED REFUSE
AREA
SLURRY POND
A
A
SPILLWAY

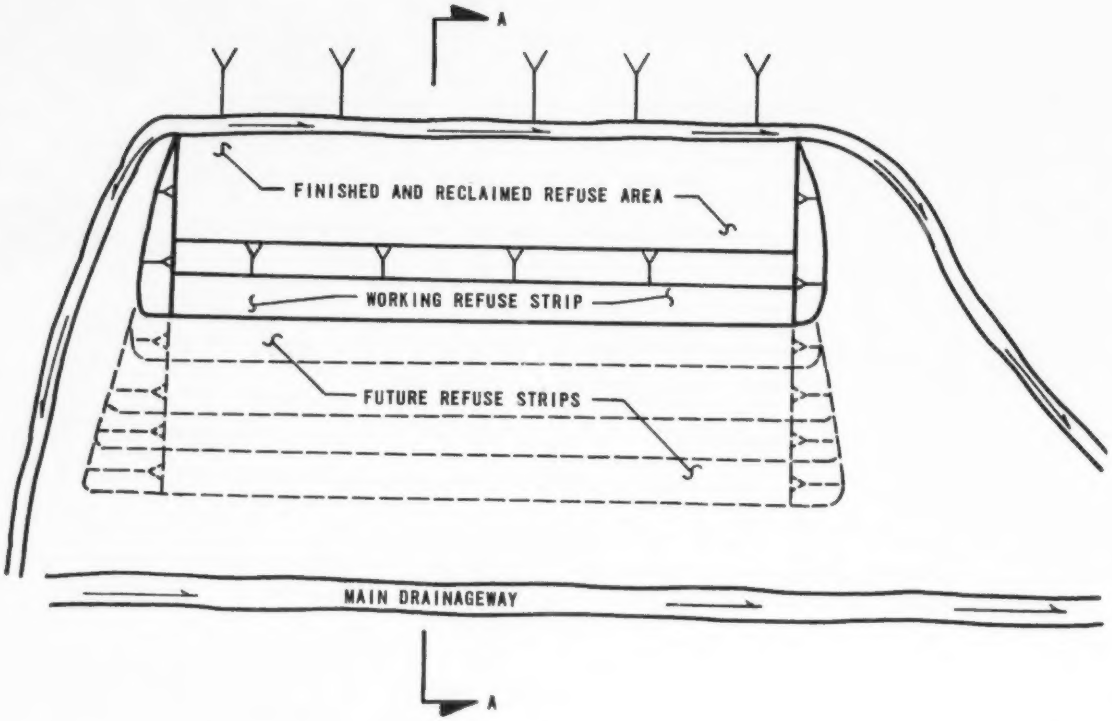
PLAN OF DISPOSAL AREA


RECLAMATION
EARTH COVER
FINISHED
REFUSE SURFACE
ACTIVE
REFUSE AREA
SLOPE
FUTURE REFUSE
DEVELOPMENT
SLURRY POND
SUBDRAIN SYSTEM
IF REQUIRED

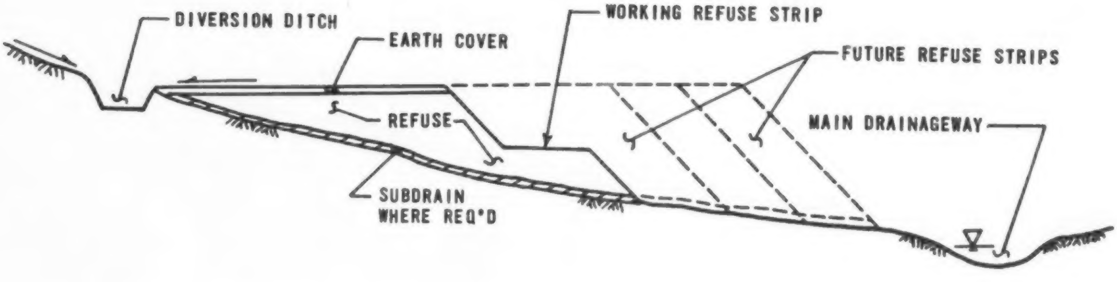
SECTION A-A

Figure 14. Site development: valley-fill refuse pile.

Figure 15 is a site development example for a side-hill refuse pile. The development is very similar to that for a valley-fill pile, except that a permanent ditch is constructed immediately above the upper limit of the pile. Both the uphill natural drainage and the drainage off the covered refuse pile are directed into this ditch. From a pollution control standpoint, a side-hill pile can most advantageously be constructed in perimeter strips, starting from the uphill diversion ditch. Topsoil removed for a new perimeter strip foundation is placed on the top finished refuse surface as part of the ongoing reclamation of the facility.


A
FINISHED AND RECLAIMED REFUSE AREA
WORKING REFUSE STRIP
FUTURE REFUSE STRIPS
MAIN DRAINAGEWAY
A

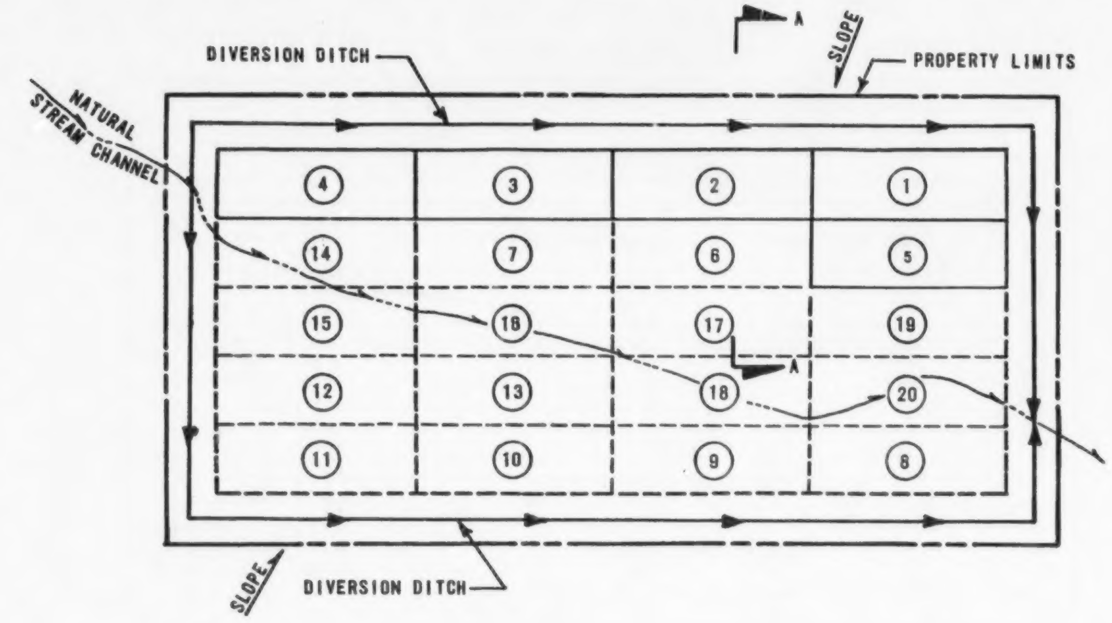
PLAN OF SIDE-HILL REFUSE PILE


DIVERSION DITCH
EARTH COVER
WORKING REFUSE STRIP
FUTURE REFUSE STRIPS
REFUSE
MAIN DRAINAGEWAY
SUBDRAIN
WHERE REQ'D

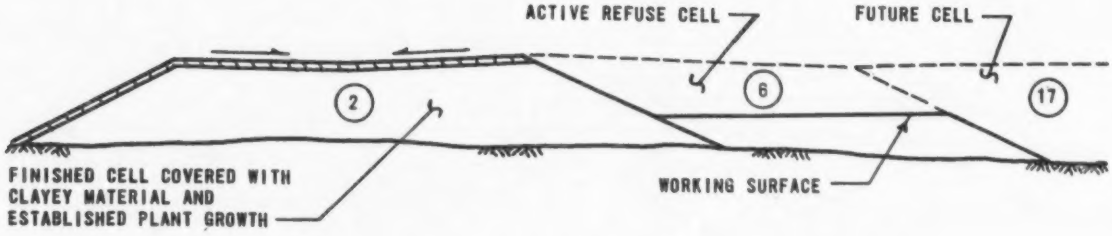
SECTION A-A

Figure 15. Site development: side-hill refuse pile.

Figures 16 and 17 illustrate two types of site development arrangements for waste heap refuse piles. Figure 16 shows a cellular system which is similar to the way many sanitary landfills are developed. The object here is to build and reclaim individual cells, in order to minimize exposed surfaces and thus reduce the water pollution potential. Cell dimensions should be the minimum consistent with safe, effective construction. The cells are usually rectangular, to facilitate refuse placement operations. In this example the


A
SLOPE
DIVERSION DITCH
PROPERTY LIMITS
NATURAL STREAM CHANNEL
4
3
2
1
14
7
6
5
15
16
17
19
A
12
13
18
20
11
10
9
8
SLOPE
DIVERSION DITCH

PLAN OF REFUSE PILE

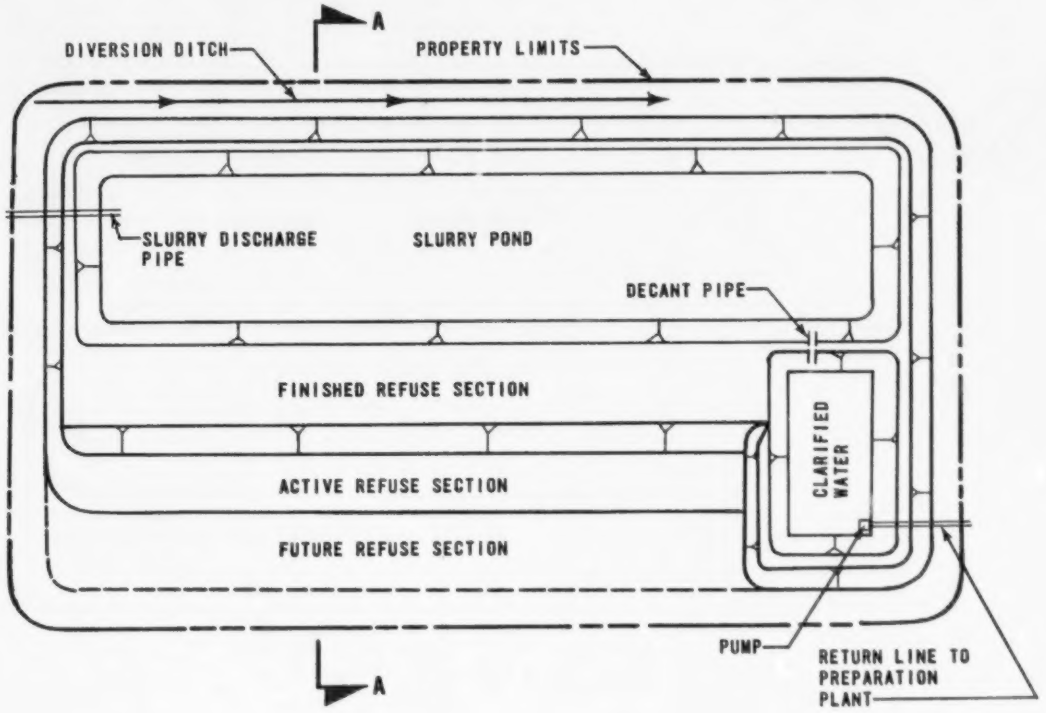

ACTIVE REFUSE CELL
FUTURE CELL
2
6
17
FINISHED CELL COVERED WITH CLAYEY MATERIAL AND ESTABLISHED PLANT GROWTH
WORKING SURFACE

SECTION A-A

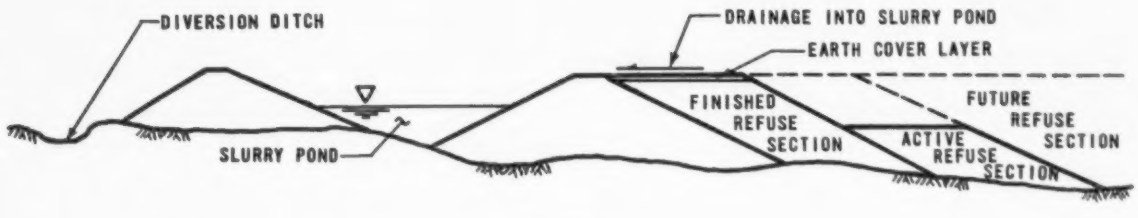
Figure 16. Cell development plan for waste heap refuse pile.

cell construction sequence was developed in such a way as to maintain site drainage. Other equally satisfactory sequences could be utilized. As for a side-hill pile, topsoil removed from beneath the foundation of a new cell is placed directly on the surface of a finished cell, as part of the ongoing reclamation work.

Figure 17 shows a waste heap pile developed in conjunction with a slurry pond. The pile is developed in a manner similar to that for the side-hill


A
DIVERSION DITCH
PROPERTY LIMITS
SLURRY DISCHARGE PIPE
SLURRY POND
DECANT PIPE
FINISHED REFUSE SECTION
CLARIFIED WATER
ACTIVE REFUSE SECTION
FUTURE REFUSE SECTION
PUMP
RETURN LINE TO PREPARATION PLANT
A

PLAN OF ALTERNATIVE REFUSE PILE


DIVERSION DITCH
DRAINAGE INTO SLURRY POND
EARTH COVER LAYER
SLURRY POND
FINISHED REFUSE SECTION
FUTURE REFUSE SECTION
ACTIVE REFUSE SECTION

SECTION A-A

Figure 17. Alternative development plan for waste heap refuse pile.

pile (Figure 15). This type of arrangement may be satisfactory for nonacid-producing refuse, but for acid-producing refuse the cellular type of system (Figure 16) is preferable.

These examples reflect some of the major pollution control considerations associated with relatively simple types of refuse piles. When slurry ponds are used in conjunction with piles, adherence to the basic principle of emplacing the coarse refuse above the slurry pond will improve pollution control and may eliminate the need for separate siltation basins.

The severity and type of water pollution problems vary with the chemical characteristics of the refuse and with specific site conditions. However, acid drainage from the pile and drainage waters containing excessive amounts of suspended or dissolved solids are always a concern. Therefore, site development plans should be directed at isolating the refuse from the surrounding environment during the operating life of the pile as well as during abandonment activities.

DRAINAGE AND EROSION CONTROL

Throughout the preceding discussions, the critical importance of drainage and erosion vis-a-vis refuse disposal has been emphasized. Proper control of drainage and erosion from refuse piles is a vital part of pollution control. Coarse refuse is usually highly susceptible to erosion--extremely deep and extensive erosion gullies can develop in a refuse pile if drainage provisions are inadequate. Outside surface waters should be diverted away from the pile, and drainage systems must be developed for water that falls directly on the disposal area.

The diversion of outside water is almost always accomplished with simple ditches. Because definitive criteria are lacking, sizing of diversion ditches has been determined somewhat arbitrarily in actual practice. Present EPA regulations regarding point source discharges from refuse storage areas, although not specifically directed at diversion ditches, permit waiving the effluent limitations for runoff that results from a 10-year, 24-hour precipitation event. We believe this is a reasonable criterion for sizing diversion ditches for sites where there is no downstream impoundment. For waste heaps, the failure, or overflow, of a diversion ditch is normally not a critical concern. In gently sloping terrain, where heavy runoffs may result in ditch overflows and perhaps in saturation of the toe of the refuse pile, ditch maintenance is usually restricted to periodic cleaning of sediments and erosion control. On the other hand, the failure of a diversion ditch above a refuse pile can result in heavy erosion and downstream water pollution. In this case large, concentrated flows of water are directed over the pile. Experience at study site E indicates that substantial maintenance is required for ditches excavated along steep, unstable, wooded hillsides, even if the ditches are designed and built in accordance with present MSHA regulations.

Surface drainage off the refuse pile itself is another important factor. The surface of the pile should always be sloped away from the side slopes, to avoid erosion problems. Where collected surface drainage must be brought down the face of a refuse pile, as is the case with a waste heap, special erosion resistant ditches should be provided. These ditches might be lined with riprap or other suitable material to control erosion. Also, the working refuse surface should be as flat as possible in order to minimize erosion, but should still have sufficient grade to ensure positive runoff without shallow ponding of waters. This is particularly important if the refuse is acid-producing. For example, at site E, surface grades were initially specified at 0.5 percent. However, controlling grades to this flat a slope was not practical, and minor ponding of waters resulted. Site operating personnel therefore selected a 1.5-percent surface slope, which was found to be satisfactory with respect to removing the water without ponding or serious erosion.

Although the primary control on erosion is proper drainage, it is also important to cover finished refuse surfaces immediately with earth and to establish a vegetative growth. This is really a part of reclamation activities, and is therefore addressed in Section 9 of this report.

DUST CONTROL

In Section 6, we discussed the various means used to transport coal refuse from the preparation plant to the disposal area. Once the coarse refuse reaches the disposal area, rubber-tired wheeled vehicles are used almost exclusively to haul and place the refuse. (This is principally because of MSHA regulations that require the refuse to be placed in layers not more than 60 cm (2 ft) thick.) Haulage equipment is usually used to compact the refuse.

The principal pollution control consideration associated with haulage in the refuse disposal area is dust control on the haul roads. Large dust clouds from haul roads are objectionable for reasons of operator health and safety and air and water pollution. Disposal areas where several pieces of equipment operate in set traffic patterns usually have one or more water trucks available to wet down the roads and reduce the dust problem.

The degree of haul roads dust control required is almost entirely dependent on the size and location of the refuse disposal operation. Haul road dust control requirements should be established on a site-by-site basis. At some sites (for instance study site C) haul road dust control is not necessary because of short haul distances, the use of only one piece of hauling machinery, and the remoteness of the site from heavily populated areas. Other sites (for example study sites B, E, and H) require haul road dust control procedures principally for reasons of operator safety and health.

Control procedures usually involve the use of water trucks to wet down the surface of the haul road. Other procedures include utilization of film or hygroscopic chemicals, sprinkler systems, or paving. In freezing weather, dust control requires special attention to avoid icing.

REFUSE PLACEMENT

Refuse placement procedures should be planned to prevent materials segregation and to minimize the seepage of moisture into the pile. In the past, materials segregation has been a chief cause of water and air pollution from coal refuse piles. Placement procedures that have caused serious material segregation have involved the use of trucks or aerial tramcars to push or dump refuse over the edges of steep slopes (see Figures 18 and 19).

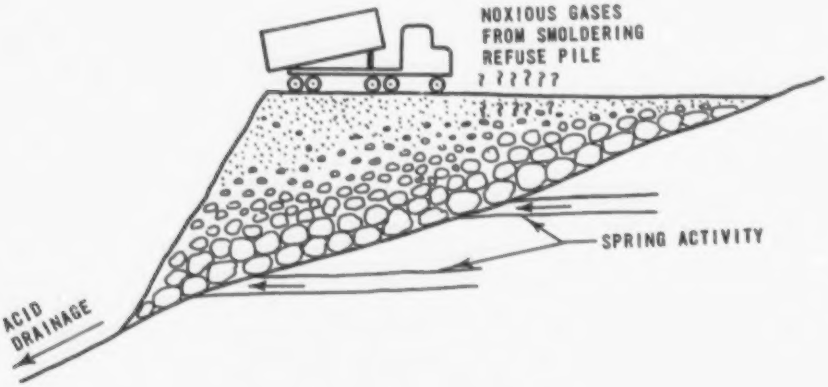

NOXIOUS GASES
FROM SMOLDERING
REFUSE PILE
SPRING ACTIVITY
ACID
DRAINAGE

Figure 18. Improper refuse placement by truck dumping.

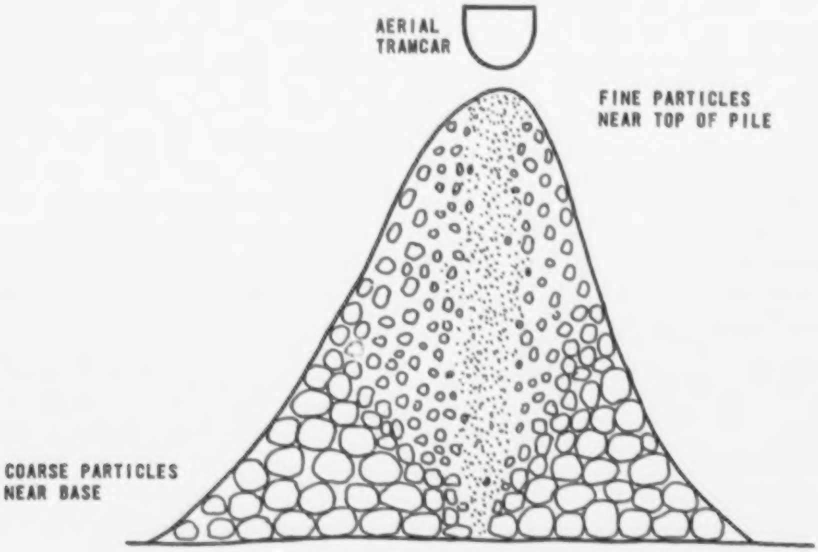

AERIAL
TRAMCAR
FINE PARTICLES
NEAR TOP OF PILE
COARSE PARTICLES
NEAR BASE

Figure 19. Improper refuse placement by aerial tramcar dumping.

When refuse falls down a steep slope, the coarse particles roll toward the bottom and the fine particles tend to remain near the top. The result is a loose, highly segregated refuse pile whose base is much more permeable than the top. It is not uncommon to find large water flows passing through the bases of old piles of this type. If the refuse is acid-producing, clean waters entering the pile become acidic and develop high concentrations of dissolved solids. Also, because the air permeability in such piles grades from high near the bottom to low near the top, smoldering fires within the mass of the refuse pile are common. The end result can be a combination of acid drainage that releases water pollutants to the downstream drainage basin and pollution from the smoldering fires that release sulfurous or other noxious gases to the surrounding atmosphere.

It is important to minimize the infiltration of water into acid-producing refuse before the materials are compacted. This particularly applies to disposal operations that use dump trucks for hauling refuse. It is common practice for the trucks to dump refuse in loose piles which are periodically leveled and compacted with a bulldozer. The refuse as dumped from trucks is loose and highly permeable and rain or snowmelt easily percolates through the material, which greatly increases the pollution load of seepage water. A case in point was described by one of the operating personnel at study site D. This disposal operation involves a wide, cross-valley refuse embankment which retains a slurry pond. Coarse refuse is truck-hauled and dumped in piles on the embankment. The working surface of the refuse is sloped into the slurry pond for sediment control purposes. Operating data indicate that drainage from the acid-producing refuse into the pond did not seriously affect the water quality of the pond and that the water level in the reservoir could be controlled by periodically pumping water which met the EPA point source discharge regulations into the public stream. During one winter period, several loose piles of refuse had been dumped on the working surface. Operational procedures called for periodic leveling and compacting of the piles; however, in this instance the piles were allowed to stand for a longer than normal period. A heavy snowfall occurred which prohibited work on the piles. Later, the snow melted and percolated slowly through the loose refuse. The resulting drainage into the slurry pond carried such high pollution loads that the entire pond required lime treatment before the water could be safely discharged into the public stream. Past experience indicated that, if the piles had been leveled and compacted, the snowmelt would not have resulted in this high pollution load.

Leveling and compacting dumped refuse do not normally constitute a full-time operation for a bulldozer. As a consequence, this work is done on an "as required" or "when convenient" basis rather than on an established schedule. The basic requirement is that acid-producing piles be leveled and compacted prior to a precipitation event which results in runoff. It is not always possible to meet this requirement, because of weather uncertainties. Nevertheless, some reasonable guidelines are necessary for limiting the amount of loose, truck-dumped, acid-producing refuse that can be placed prior to leveling and compaction. Two suggested methods, which may be used separately or in combination with each other, are;

1. To require leveling of piles on an established periodic basis, for example at least once every working shift. Also, when rain or snow is predicted, leveling and compacting equipment should be active on the working surface.

2. To limit the exposed working area where refuse is being placed so that an excessive pollution load will not be released to downstream waters during and after a precipitation event.

The second method is the most desirable, because it would minimize not only pollution loads from water seeping through the refuse but also the loads from water running off the surface of leveled and compacted refuse. Although there are no quantitative data available from which to develop guidelines for limiting exposed acid-producing refuse surfaces, it is best to keep such surfaces to the minimum consistent with efficient and safe construction practices.

LIFT THICKNESS

MSHA regulations specify that the lift thickness of coarse refuse be not more than 60 cm (2 ft). As indicated in the tabulation below, the study sites use lift thicknesses substantially less than this.

	Owner-Specified Lift Thickness		Actual Lift Thickness		
Site	Centimeters	Inches	Centimeters	Inches	Haulage Equipment Used
B	20 - 30	8 - 12	10 - 30	4 - 12	Scrapers
C	60 (max.)	24 (max.)	15 - 30	6 - 12	Scrapers
D	60 (max.)	24 (max.)	30 - 45	12 - 24	Trucks
E	20 - 30	8 - 12	10 - 30	4 - 12	Scrapers
F	45 - 60	18 - 24	30 - 45	12 - 18	Trucks
G	45 (max.)	18 (max.)	30 - 45	12 - 18	Trucks
H	60 (max.)	24 (max.)	15 - 30	6 - 12	Scrapers

The principal reason given by site operators for using lift thicknesses thinner than required is improved trafficability. They have learned through experience that the thinner the lift, the easier it is for vehicles to travel over the material without creating excessive tire rutting. Having a firm, unyielding surface for the haul units improves productivity and decreases operating and maintenance costs.

The tabulation above also shows that when scrapers are used to haul and place refuse, the lift thickness is usually substantially less than when trucks are used. Scrapers are designed to place materials in thin lifts, and they are also expected to operate fairly independently of bulldozers. When trucks are used for refuse hauling, the material is dumped in piles which are periodically leveled and compacted with a bulldozer, which has no trafficability problems and thus can spread the refuse in thicker lifts than a scraper can.

COMPACTION

Lift thickness should be determined in relation to the required compactive effort--the thinner the lift, the less the compactive effort required. In general, the cleaner or more permeable the material, the easier it is to compact and the greater the allowable lift thickness. Compaction has a significant effect on the permeability of the emplaced refuse, and this in turn affects the pollution load in waters discharged from the pile.

Compaction is required, in most engineering applications, primarily to increase refuse strength and decrease compressibility. For pollution control, compaction is required primarily to reduce the air and water permeability of the material. Reducing air permeability reduces the potential for spontaneous combustion, which leads to refuse pile fires and thus to air pollution. Reducing water permeability reduces moisture infiltration into the refuse and thus reduces the pollution potential for waters leaving the pile.

Only limited data are available about the effects of compaction on refuse permeability. Most of the reported work has been done in the laboratory, using rammer-type hammers to compact reconstituted samples. Unfortunately, the sampling and testing processes tend to degrade the shale refuse, so that the percentage of fines in laboratory-test samples is often greater than that in in-situ materials. Thus, laboratory data may not accurately represent field conditions.

In a laboratory study of retorted oil shales,[13] which have properties similar to those of coal refuse, the effects of different compactive efforts on permeability were investigated. The results of this program indicate that, at a low compactive effort, permeability (K) = 480 - 2,088 x 10^{-6} cm/sec; at a medium compactive effort K = 41 - 157 x 10^{-6} cm/sec; and at a high compactive effort K = 16 - 51 x 10^{-6} cm/sec.

The earth-dam engineering permeabilities of soil can be classified as shown below:

Permeability (cm/sec)	Classification
Greater than 10^{-4}	Pervious
10^{-4} to 10^{-6}	Semipervious
Less than 10^{-6}	Impervious

Accordingly, material tested at low, medium, and high compactive efforts can be classified as pervious, pervious to semipervious, and semipervious, respectively. Also, refuse material placed with a high compactive effort can be as much as 100 times less permeable than refuse placed with a low compactive effort.

Compaction of refuse reduces the permeability of the mass by pushing the refuse particles closer together and breaking down some of the large particles into smaller particles, thus increasing the percentage of fines. Both of these mechanisms reduce the void ratio and porosity of the refuse mass. The reduction of voids by pushing the particles closer together is more pronounced with well-graded materials. The greater the range of particle sizes, the greater the reduction in voids for a given compactive effort. The more poorly graded the refuse, the less will be the effect of compaction on reduction of voids. For example, refuse from the rotary breaker in the preparation plant is very poorly graded. Compaction of this material, assuming no particle breakdown and resultant increase in fines, has only a minor effect on permeability.

Refuse breakdown into smaller particles for a given compactive effort is primarily a function of type of equipment used and angularity and hardness of the particles. Fortunately, from a permeability or water infiltration standpoint, the vast majority of coal refuse is a soft shale or clay shale, which is degradable with exposure to weather and mechanical handling or compaction. The anticipated effects of various types of compaction equipment on breakdown or degradation of refuse particles may be summarized as follows:

Type of Compaction Equipment	Anticipated Effect on Refuse Degradation	Remarks
Rubber-tired trucks scrapers, rollers	Low	--
Bulldozers and grid compactors	Low to moderate	Fines generated primarily at surface
Smooth drum static and vibratory rollers	Low to moderate	"
Sheepsfoot rollers	Moderate to high	Approximates rammer-type laboratory compaction test effects
Vibratory sheepsfoot	High	"

For acid-producing refuse or refuse utilized in constructing the core of a water and/or slurry retention dam, the percentage of fines is a critical factor in minimizing infiltration. For these situations it is advisable to use equipment which will maximize degradation and produce an optimum percentage of fines. Alternatively, fines (such as fine coal refuse or selected borrow) can be mixed with the coarse refuse. In several earth-dam technology applications a material with insufficient fines has been modified so that the end result had sufficient fines.[14-18] In these cases physical means were used to increase fines and reduce the permeability of soil-rock materials. Also, Sherard[19] suggests that wetting the material and allowing it to weather is another method of increasing fines. Other possible methods include using heavy industrial-type disks on thin refuse lifts to crush some of the soft shale particles and thus create additional fines, or adding fines from the fine coal refuse circuit in the preparation plant.

In earth-rock dam technology, one of the main concerns in using soft rock materials such as coarse coal refuse is that the materials may soften appreciably with time and with exposure to air and water. However, if there are enough fines to fill the voids, and if the fines are reasonably well compacted at the proper water content, no significant embankment softening will occur.[19] Therefore, increasing the proportion of fines to reduce permeability (and thus to make the material more acceptable environmentally) also adds to the integrity of the structure.

Most pile compaction uses hauling and/or spreading equipment. When the refuse is used as structural fill, special compactors are used. (For example, at site I, where the downstream portion of the dam is being constructed of refuse, an 11-ton, smooth drum, vibratory roller is used for compaction.) When the refuse is used as a nonstructural fill, only random travel of the hauling equipment is usually specified (this requirement is sufficient to meet present MSHA regulations). Among the study sites, only site G has a more definitive criterion for compacting with hauling equipment. Here the drivers are instructed to change their truck paths so that each refuse layer is compacted by at least four to six coverages of the truck wheels. When rubber-tired equipment is used for compaction, it is vitally important to maintain proper tire pressures.

Sawyer and Fredland[20] found that, given equal lift thicknesses and an equal number of compaction passes, the coal waste compaction achieved using a scraper is substantially greater than that obtained using a bulldozer. These findings have been substantiated by field observations and by the expressed opinions of the construction and mining industries.[21] Although definitive field data are not yet available, it is also the general opinion that scrapers are superior to conventional on-highway trucks in the degree of compaction achieved by random routing of equipment.

In the last 20 years or so the use of thin lifts and heavy rubber-tired equipment has also been adopted by the electric power industry for compaction of large coal storage piles adjacent to power plants. Most coal-fired utility plants keep a 60- to 90-day supply of coal on hand to help ensure uninterrupted power generating capability. As the size of the generating plants has increased, so has the size of the coal storage piles. Prior to the 1960s, many of these coal piles ignited basically for the same reasons as did some older coal refuse piles. Such fires presented an economic loss to the utilities, and immediate action was usually taken to extinguish the fires or hot spots by digging them out and wetting down the exposed hot coals. However, as coal preparation plant processes changed so that coal received at the plants had a greater proportion of fines, and as large, rubber-tired bulldozers that operate most effectively on thin lifts became more widely available, the problem of coal storage pile fires was practically eliminated. This is because it became possible to reduce the air permeability of the pile mass so much that there would no longer be sufficient oxygen to support the ignition mechanism.

Another adverse environmental feature of older coal storage piles that has largely disappeared today was the underdrain system. Formerly, many storage piles were constructed on a permeable base of sand, to facilitate drainage and supposedly to reduce the moisture content of the coal. These underdrain systems probably added to the amount of air available to the interior of the pile and thus increased the potential for pile ignition. Because today's storage piles are tight and relatively impermeable, they do not require underdrain systems. Not only has the air pollution potential been reduced, but also, because water infiltration into the pile has been minimized, the potential for water pollution has been reduced.

Certain factors should be considered with regard to compaction equipment type and operation. The following factors are particularly important. In choosing bulldozers, crawler types with conventional tracks are generally best. Bulldozers with wide tracks are used for work on soft ground where low contact pressures are critical. Low contact pressure, or flotation track, bulldozers are unsuitable for use as compaction equipment. When using on-highway trucks for compaction, special attention and control are required to obtain reliable routing of the trucks over the pile. Because on-highway trucks are particularly sensitive to surface irregularities, they tend to follow one relatively smooth path over the pile, except in the immediate dumping area.

PILE OPERATION IN ADVERSE WEATHER

During prolonged periods of heavy rain or snow, or when temperatures are well below freezing, special or modified disposal operations are sometimes required, depending on site conditions, types of equipment used, and severity of the weather. In conventional earthworks construction, operations are stopped when weather conditions are poor. In contrast, coal preparation plants must operate in all weather conditions, in order to maintain efficiency. Therefore there must either be temporary refuse storage provisions or procedures must be adopted to permit refuse placement during adverse weather.

For inclement weather operations, the working area should be kept to an absolute minimum. At some sites (particularly at sites in Great Britain), special areas are designated for use in bad weather. These areas are usually readily accessible and are located in noncritical sections of the site, and remote or critical sections are used only in favorable weather.

In periods of prolonged rainfall, trafficability is reduced, equipment may be mired down, and ruts that collect water are created in the refuse surface, which adds to the water pollution potential and to site accessibility problems. These difficulties are particularly acute at sites that have long, steep haul roads and that use on-highway trucks for refuse hauling. To minimize rainfall effects, refuse area surfaces should be sloped to drain and compacted to a hard, tight surface. The object is to drain away the rainfall as rapidly as possible, so that it does not excessively soften the surface or infiltrate the refuse mass.

Snowfall can also affect operations and pollution control procedures, especially with respect to water pollution loads. The amount of pollutants picked up by water is related to contact time. When small amounts of water trickle over refuse, the pollution load picked up is substantially greater than that to be expected from an equal amount of water from a sudden rainfall. Therefore, acid-producing refuse piles should be leveled and compacted prior to a snowfall, to minimize moisture infiltration during the snowmelt. Also, refuse should not be placed without first clearing snow from the working surface. Placing refuse on a snow blanket not only increases the pollution potential but can seriously affect the stability of the pile when the snow melts. If possible, cleared snow should be piled at a location away from the refuse surface. Care should be taken to keep the piled snow out of diversion ditches, so as not to obstruct snowmelt drainage.

Another weather-related event that can affect pile operations is a period of freezing weather. Most refuse comes out of the preparation plant quite wet. Refuse particles may then freeze together in large lumps, creating handling problems for trucks, conveyors, and storage bins. A principal concern with placing refuse in freezing weather is the inability to achieve satisfactory compaction. In summary, and as a general guideline, it can be said that refuse placed during freezing weather should be disposed of only in special, noncritical areas.

SUMMARY OF PRINCIPAL PILE CONSTRUCTION AND OPERATION GUIDELINES

- Only immediate work areas should be cleared and grubbed.

- Burning of cleared and grubbed debris should not be permitted unless approved by regulatory agencies.

- No debris or organic material should be disposed of in the refuse pile.

- Topsoil from under the proposed pile should be removed, and should be stockpiled for future use in reclamation unless steep terrain or other considerations make this impractical.

- Foundation subdrains should be provided in areas where there are springs.

- Surface waters should be diverted around all refuse piles.

- Drainage from piles should be directed into siltation basins until the piles become inactive and have been covered and adequately protected against erosion.

- A valley-fill pile should be developed starting at the head of the valley.

- Waste heaps are best developed using cellular construction methods.

- Side-hill piles should be developed in perimeter strips.

- Cross-valley piles should be avoided wherever possible.

- Exposed pile surfaces should be minimized and finished surfaces should be reclaimed.

- Refuse surfaces should be sloped to drain away from side slopes.

- Active surfaces should be as flat as possible, to minimize erosion, but should be steep enough to permit positive drainage without shallow ponding of waters.

- Haul road dust control requirements should be established on a site-by-site basis.

- Refuse should be placed using methods that minimize material segregation. Dumping refuse over steep slopes is specifically not recommended.

- Truck-placed piles of refuse that are potentially acid-producing should be leveled and compacted at least once during every working shift.

- Lift thicknesses of placed refuse should be 60 cm (2 ft) or less.

- Nonstructural refuse embankments may be compacted satisfactorily by planned routing of construction equipment over thin lifts.

- Loaded scrapers are more effective for compacting refuse than are bulldozers or on-highway trucks.

- Specially designated noncritical portions of a disposal site should be reserved for refuse placement during inclement weather.

- When rubber-tired equipment is used for compaction, it is very important to maintain appropriate tire pressures.

SECTION 8

GUIDELINES FOR SLURRY POND CONSTRUCTION AND OPERATION

Disposing of fine waste in slurry ponds is generally the most efficient and economical disposal method. The basic process of pumping a mixture of water and solids into one end of a pond, allowing the solids to settle out in the calm water, and discharging the clarified water at the other end of the pond is simple and effective.

The most critical concern with respect to slurry ponds is the safety of the retaining dam. In the past, many slurry retention dams were constructed without adequate provisions for embankment stability or for safe handling of flood waters. Today, with the advent of strict MSHA regulations and mine owners' greater awareness of safety considerations, such problems are gradually being resolved.

From a pollution control standpoint a well sited, designed, and operated slurry pond has several important features that make it superior to a refuse pile. First, the vast majority of the refuse in a slurry pond is submerged during the operating life of the facility. Oxidation of pyritic materials and the resulting production of acid are thereby effectively eliminated. In contrast, acid-producing refuse in a dry landfill cannot be totally isolated to avoid acid drainage.

Except for the retaining dam or dike system, the detailed and careful provisions for erosion control and refuse placement and compaction required for a refuse pile are not required for a slurry pond. Also, dust control from active slurry ponds does not usually present a significant problem. And finally, a properly operated slurry pond with all of the refuse under water can be much more aesthetically pleasing than an active refuse pile.

Although slurry ponds do have these advantages, they can nevertheless contribute significantly to water pollution. The most common pollution control concern is the carryover of suspended solids from the ponds into public streams. Chemical pollution of slurry pond waters which are not recirculated can also be of concern, particularly if significant amounts of soluble salts or lime are associated with the refuse.

SLURRY POND WATER CIRCUITS

Ponds that discharge clarified sluicing waters into public streams are classified as "open" systems, and ponds that return clarified sluicing water back to the preparation plant for reuse are termed "closed" systems. There is considerable debate concerning classifying pond systems as "closed," since there are always some water losses out of ponds from seepage or storm overflows. However, because of increasing environmental concerns and the scarcity of adequate water supplies in certain parts of the country, many slurry pond water circuits are being closed as far as possible. Of the seven slurry pond systems investigated in this study, for example, three are closed systems.

Closed Circuits

A closed water circuit, as used here, is defined as a circuit that recycles slurry water back to the preparation plant for reuse; also, in this circuit the seepage losses out of the pond are minimal. The principal operating problem is buildup of dissolved solids in the water as it is constantly reused. At two of the study sites, the plant operators mentioned that their principal objection to the closed circuit was the buildup of dissolved salts in the recirculated waters. These salts were adversely affecting some preparation plant operations and the integrity of some of the structural components in the plants.

A closed circuit usually includes rather large, separate clarified water ponds. Separation of these ponds allows operation of the return water pumps without having to be concerned about drawing slurry water with high concentrations of suspended solids.

It should be noted that a closed circuit still requires a source of makeup water. In coal cleaning, the preparation plant uses substantial quantities of water that is not returned to the circuit. Coal as shipped generally has a higher moisture content than its natural moisture content. Evaporation and seepage cause additional water losses.

For a slurry pond to operate effectively with a closed water circuit, outside drainage waters should be diverted around the pond to avoid overloading the retention capacity of the pond and spilling excess waters into public streams. Also, slurry pond sites with pervious substrata should be avoided or properly sealed off.

Open Circuits

In an open water circuit, free water is not recycled but is discharged from the pond to the public streams on a continuous or regular basis. Suspended solids are of considerable concern in open water circuit ponds that discharge fairly regularly to public streams.

The amount of suspended solids discharged depends on pond efficiency and operating procedures. Most ponds have a single point discharge opposite a decant pipe. At the study sites, the refuse solids are allowed to build up above the water line near the discharge point, and form a delta extending toward the overflow decant structure. The farther the delta extends toward the decant structure, the greater the amount of suspended solids discharged, because settling time in free water is reduced. Discharge water is sampled periodically and, when the concentration of suspended solids approaches the maximum permitted by the regulatory agencies, operations are modified to increase the free-water path between the discharge and decant points.

In an open water circuit system it is difficult to minimize suspended solids during storms. This is especially true at sites which have large drainage areas above pond level from which runoff flows directly into the pond. Pond efficiency is drastically reduced because of the greater quantities and higher velocities of water passing through the pond. Even more significant is the scouring action of fast-moving, turbulent streams entering the ponds and the physical erosion and resuspension of solids previously deposited. These solids are literally flushed out of ponds into downstream receiving streams. A typical situation of this sort is shown on Figure 20.

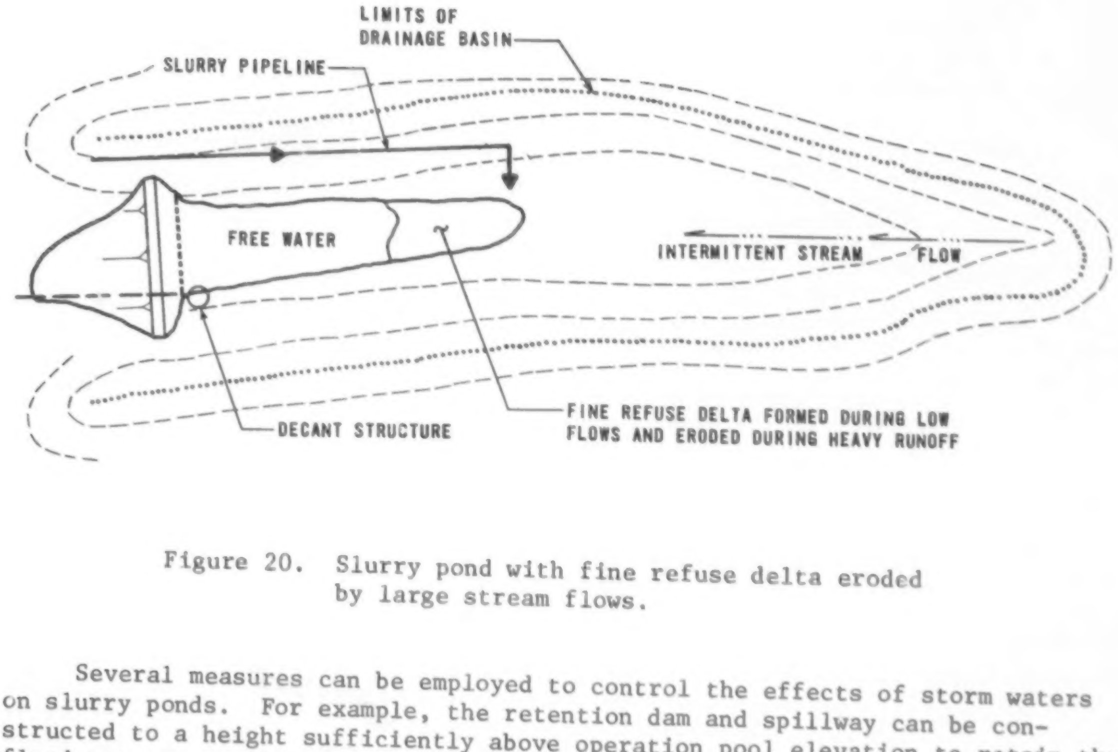
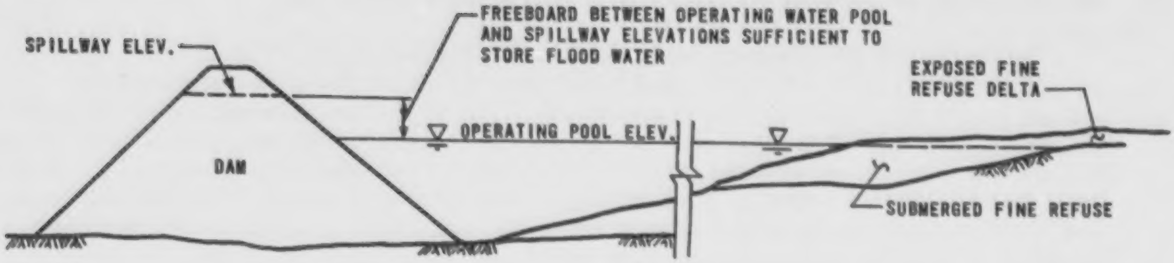

LIMITS OF DRAINAGE BASIN
SLURRY PIPELINE
FREE WATER
INTERMITTENT STREAM
FLOW
DECANT STRUCTURE
FINE REFUSE DELTA FORMED DURING LOW FLOWS AND ERODED DURING HEAVY RUNOFF

Figure 20. Slurry pond with fine refuse delta eroded by large stream flows.

Several measures can be employed to control the effects of storm waters on slurry ponds. For example, the retention dam and spillway can be constructed to a height sufficiently above operation pool elevation to retain the flood waters, as illustrated schematically on Figure 21. Routine clear-water decanting would then be accomplished by pumping over the dam rather than discharging through a gravity-flow decant structure. (This method is in use at Sites B and D.) Most preparation plants operate only two shifts, so pumping of excess water is usually done prior to the start of sluicing operations in


SPILLWAY ELEV.
FREEBOARD BETWEEN OPERATING WATER POOL AND SPILLWAY ELEVATIONS SUFFICIENT TO STORE FLOOD WATER
EXPOSED FINE REFUSE DELTA
OPERATING POOL ELEV.
DAM
SUBMERGED FINE REFUSE

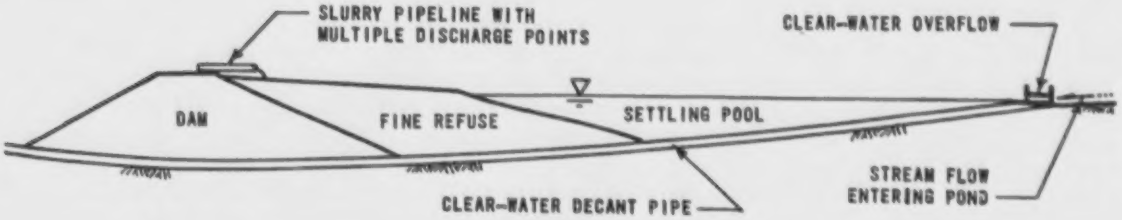
NOTES: 1. OPERATING POOL ELEVATION MAINTAINED BY PERIODIC PUMPING EXCEPT DURING HEAVY STREAM FLOWS. EXCESS WATERS ARE USUALLY PUMPED IN EVENINGS, AFTER SLURRY SLUICING OPERATIONS HAVE STOPPED AND SUSPENDED SOLIDS HAVE SETTLED.

2. SPILLWAY SHOULD BE DESIGNED TO PASS MAXIMUM PROBABLE FLOOD, AS REQUIRED BY MSHA.

Figure 21. Flood-water storage in slurry ponds to minimize downstream water pollution.

the morning. This allows the maximum time to permit suspended solids to settle out before the water is discharged downstream.

Another flood-water control method involves constructing a decant system that is aligned up a primary hollow (see Figure 22). This can reduce the adverse effects created by an incoming stream that scours away previously


SLURRY PIPELINE WITH MULTIPLE DISCHARGE POINTS
CLEAR-WATER OVERFLOW
DAM
FINE REFUSE
SETTLING POOL
STREAM FLOW ENTERING POND
CLEAR-WATER DECANT PIPE

NOTE: RETENTION DAM IS RAISED AND CLEAR-WATER DECANT PIPE IS EXTENDED AS REQUIRED TO DEVELOP ADDITIONAL STORAGE CAPACITY.

Figure 22. Upstream slurry discharge system. Note clear-water decant pipe in upper reaches of settling pool.

deposited refuse. Still another type of control can be achieved by providing a sufficient depth of water in the pond to prevent scouring by incoming waters and to allow settlement of suspended solids during storms.

Finally, it is theoretically an acceptable approach to construct diversion ditches around a slurry pond, designed so that the ditches discharge waters below the slurry pond dike or dam. In practice, however, this approach is not always reliable, particularly for use in steep terrain where landslides and debris can cause diversion system failures just when the ditches are needed most during heavy storms. A diversion ditch collects water from uphill areas and concentrates it on one large stream; if the ditch is breached, overflowing waters can create concentrated flow paths and thus lead to highly erosive action across the pond.

The measures mentioned above are applicable to slurry ponds where there are large drainage areas above pool elevation. For ponds with no significant drainage area above pool elevation (for instance diked ponds), the storm-water problem is usually not so severe. The primary effect in these cases is a loss of pond efficiency, due to a greater discharge velocity. Scouring action is not pertinent because there are no large, concentrated, incoming flows. During severe storms, incoming waters may exceed the storage capacity of a pond and the mixed slurry and storm waters may pass over the spillway.

To summarize, it is usually not reasonable or necessary to design slurry impoundments with major outside drainage areas to retain the water from a probable maximum precipitation event. Some overflow from such impoundments should always be expected. Present EPA guidelines permit effluent discharges during, and four hours after, an event larger than a 10-year, 24-hour-frequency storm. A slurry pond with an open-water circuit should therefore be designed to retain the water generated by a storm up to this magnitude.

POND OPERATION

Control of Chemical Pollutants

The types of chemical pollutants in slurry pond waters depend in large part on the chemistry of the refuse and source water. Pollutant concentrations depend on the total water balance and on whether the water is recirculated (closed circuit) or whether it is used once and discharged from the system (open circuit). The tabulation below shows the results of chemical tests of slurry pond waters at the study sites. It is interesting to note that all the pond waters sampled had a pH near neutral or on the alkaline side. Indeed, most slurry ponds have a pH near or above 7. This fact suggests that a certain amount of untreated acid drainage water could be injected into a pond. If properly done, the water chemistry of the resultant mix might be improved over that of the original constitutents.

Site	pH	Acidity (mg/ℓ as $CaCO_3$)	Alkalinity (mg/ℓ $CaCO_3$)	Remarks
A	7.65	---	341	Closed circuit
F	7.4 - 8.3	0 - 2.0	54 - 240	Closed circuit
G	8.15	---	163	Closed circuit (seep sample)
H	8.34	---	208	Open circuit

Control of Dissolved Solids

Control of the water chemistry or the dissolved solids in a slurry pond is a difficult and complicated matter that normally requires special chemical and physical treatment. Sluicing coal refuse almost always increases the concentration of dissolved solids in water. Fortunately, these concentrations in most open-circuit slurry ponds are relatively low and fall within present regulatory requirements for point source discharges.

Control of Suspended Solids

The principal variables that affect settlement of suspended solids in a slurry pond are particle size and specific gravity of solids, kinematic viscosity of the fluid, velocity of slurry through the pond, and length of free-water surface between the slurry discharge point and the clear-water decant structure.

The tabulation below shows the effects on settling of particle size, the most significant variable with respect to efficiency of settling basins. The settling velocity of the suspended solid varies with the square of the particle diameter.

TIME AT WHICH PARTICLES WILL SETTLE
IN STILL WATER AT 10°C
(Specific Gravity = 2.65)

Particle Diameter (mm)	Material	Time Required to Settle 30 Centimeters (1 Foot)
10.0	Gravel	0.3 seconds
1.0	Coarse sand	3 seconds
0.1	Fine sand	38 seconds
0.01	Silt	33 minutes
0.001	Bacterial	35 hours
0.0001	Clay	230 days
0.00001	Colloids	63 years

Source: Reference 4.

The specific gravity of fine coal refuse normally ranges from 1.6 to greater than 2.4, depending on the composition of the materials. This is substantially less than the specific gravity of most soils, which ranges from about 2.6 to 2.7.

The kinematic viscosity of water at 1°C is about twice its viscosity at 30°C. Slurry ponds are therefore much less efficient in the winter than in the summer.

The velocity of slurry through a settling pond affects the time available for particle sedimentation and the drag forces, or resistance to downward movement, on the settling particles. The lower the velocity, the less the turbulence and the greater the efficiency of the pond. Also, the greater the length of the slurry path over free water, the more time there is available for solids to settle out of suspension.

Some sites use single point slurry discharge arrangements. After a period of time a delta of solids builds up in front of the discharge point; as this delta grows in the direction of the clear-water decant structure the amount of suspended solids increases because the slurry path over free water is being shortened. At some time the amount of suspended solids will exceed allowable limits for discharging to public streams or for use in the preparation plant. Before this occurs, operations should be modified to avoid exceeding the limitations. Traditionally, this has been done in one or more of a number of ways. For example, a diversion dike can be built out into the pond to direct the flow path of the slurry into dead areas of the pond. (This was done at sites A and D.) Also, the slurry discharge point can be moved to free-water areas around the edge of the pond, as is done at site H. Another method involves raising the pond water elevation by placing stoplogs or plugs in an appropriately designed decant structure. This is also done at site H.

Control of Other Pollutants

At many sites (for example at sites C and D), pollutants other than fine coal waste are deposited in slurry ponds for pollution control. The most common of these pollutants are acid mine drainage and/or precipitates from the chemical treatment of acid mine drainage. Another interesting example of accommodating additional pollution loads in a slurry pond is at site F, where the fresh-water lake used for makeup water purposes is contaminated with detergents from domestic sources upstream. Although this makeup water is acceptable for use in the jig water circuit in the preparation plant, it fouls the heavy media separation process. Therefore, the water with the detergent load is put into the slurry pond, so that the detergents are degraded by the dirty pond waters. By the end of the slurry pond water cycle the detergents are no longer active and the water can be cycled through the heavy media process.

Dust Control

At some sites where large, exposed refuse deltas lie appreciably above the operating pool elevation, dust problems have arisen from fines blowing off the surface. If the ponds are located near populated areas or highways, the dust clouds can be a hazard. However, this situation is not common in the eastern U.S. coal fields, because of the generally humid climate and because of the drawing up of water by capillarity through the fine, silty refuse. More serious problems of this nature are encountered during abandonment activities after the pool level is dropped and prior to covering the pond with soil. Where fines blowing off the delta of a slurry pond do create problems, the most positive remedy is to raise the operating pool level and discharge the slurry at lower points in the pond.

TEMPORARY SLURRY PONDS

If suitable property of sufficient size is not available, coal operators sometimes resort to the use of small, temporary ponds. It should be noted that many temporary ponds are so small that chemical coagulants must be added to increase the effective particle size and facilitate settling. These ponds are cleaned out periodically and solids are placed in dry storage. Because of the necessity of maintaining operations during the cleanout or reclaim period, most such systems are composed of more than one pond. Thus one pond can be cleaned while another is still in operation.

Cleaning slurry ponds is normally done with a dragline positioned along the edge of the pond, and the solids are stockpiled to facilitate drainage. A front-end loader then picks up the solids and puts them on trucks to be taken to a dry refuse disposal area--usually a coarse refuse pile.

Cleaning out the solids in a temporary slurry pond is somewhat difficult. The fine coal refuse is usually waterlogged and hard to handle with conventional earthmoving equipment. Unless physically confined, the wet solids tend to flow when stockpiled along the edge of the retaining dike. This is particularly true of the very fine solids at the lower end of a pond opposite the slurry discharge point.

In this type of operation, certain pollution control precautions are especially important. First, the refuse stockpiled from the dragline should be drained toward a sump or small retention basin to retain suspended solids and contaminated waters. Also, the trucks that haul fine refuse should be equipped with tight tailgates to minimize loss of solids along the haul road. Sometimes the fine refuse is in a semiliquid state and tends to slosh around in a moving truck. Special retention provisions are required for this situation. In final disposal activities, the fine refuse from the pond should be placed only in nonstructural fill areas, since compaction of this material is usually not practical. The fine material should be kept near the center of the coarse refuse pile, where it can be readily confined by the coarse refuse.

SLURRY RETENTION DAMS AND DIKES

The safety of embankments that retain slurry ponds is of paramount concern to coal operators and to those who live downstream of such impoundments. It is not the intent of this report to provide dam safety guidelines for water-retention embankments. Nevertheless it is appropriate to include some general comments with respect to impoundment structures from the standpoints of safety and pollution control.

Safety Considerations

An impounding embankment may fail for one or more of three principal reasons: (1) the embankment and/or its foundation have insufficient strength to resist the applied loads and a slope failure results; (2) there is insufficient spillway capacity to pass flood flows and the dam fails by overtopping; and (3) materials in the embankment or its foundation are eroded away by excessive seepage velocities (piping). Slope failures are generally the result of (1) high internal water levels caused by improperly controlled seepage through the retaining embankment and/or foundation, or (2) steep embankment slopes constructed on weak foundations. Flood-flow overtopping of a retaining embankment due to the lack or inadequacy of a spillway is the most common cause of failures of earth-type dams. Piping occurs most commonly along conduits that pass through an embankment below the water line.

Many slurry impoundment dams or dikes are constructed in stages to minimize initial capital expenditures. When a mine starts up, a low starter embankment constructed of natural materials is usually built. As the impoundment is filled with fine refuse, additional storage capacity is developed by raising the height of the retaining embankment, or by extending the embankment to adjacent areas, or by abandoning the pond and constructing a new pond elsewhere. For economic and land use reasons, the trend today is to raise impoundments to greater heights to develop the necessary storage capacity.

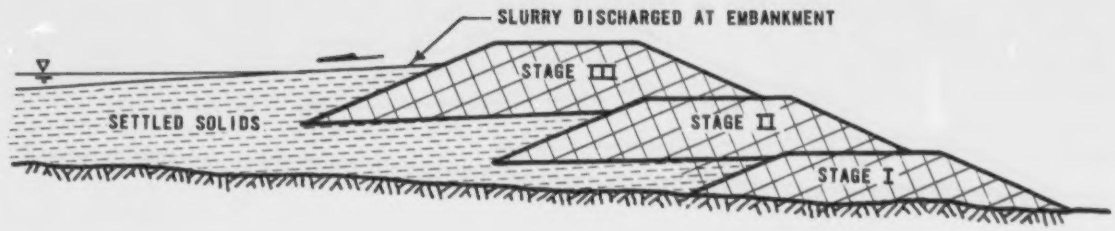
Three basic methods of raising slurry pond embankments are shown on Figure 23. From the dam safety viewpoint, the upstream method is the least desirable, and is commonly the cause of numerous stability problems. This is principally because of the weak slurry foundation and the potential for developing adverse water pressures at the junctions of the successive raises. This type of embankment is particularly susceptible to failure during earthquakes. The downstream method is normally the safest of the three, but is also is the most expensive, because larger embankment volumes are required. Regardless of the method of construction used, qualified engineers who are experienced in this field should be consulted.

Retention embankments constructed by the upstream and centerline methods usually have wide crests in order to reduce the risk of an embankment slope failure extending to the free-water pool and causing a major breach, and to create additional disposal capacity for coarse refuse.

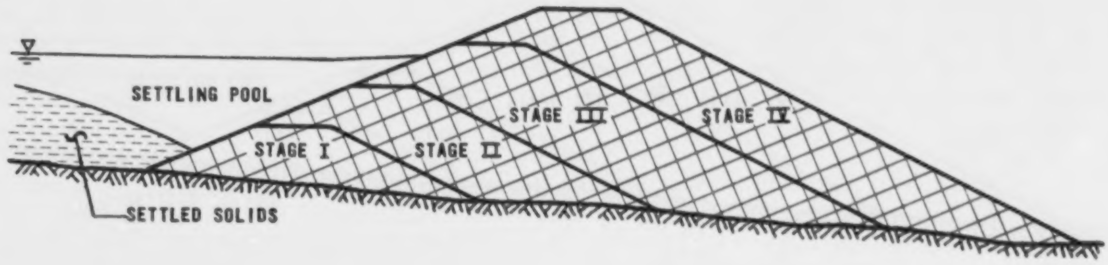
A major economic concern in staged construction of cross-valley dams with large drainage basins is the necessity for abandoning and reconstructing spillways with each successive raise in embankment height. Such spillways may represent a major portion of the construction cost in slurry pond development.

Coarse Refuse as an Embankment Construction Material

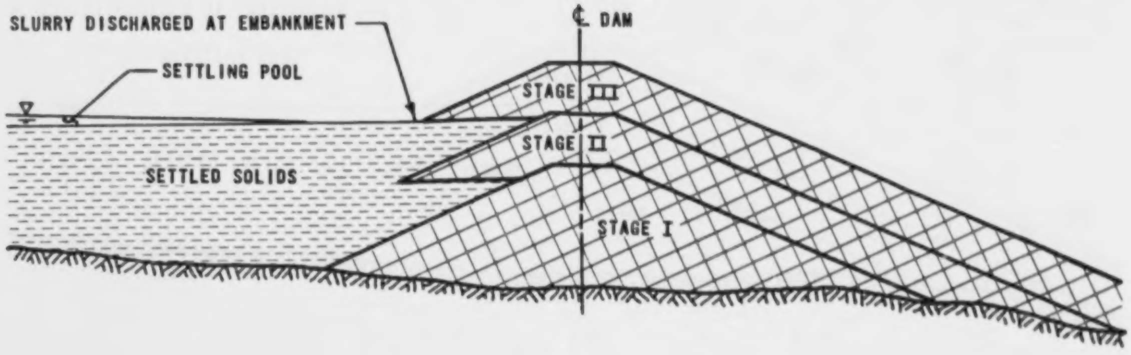
A major pollution control consideration in constructing slurry pond embankments is whether coarse refuse is a suitable construction material. The principal concern here is with seepage through acid-producing refuse. An example is the condition at site D, where approximately 7.9 liters/sec (125


SLURRY DISCHARGED AT EMBANKMENT
STAGE III
SETTLED SOLIDS
STAGE II
STAGE I

UPSTREAM CONSTRUCTION


SETTLING POOL
STAGE III
STAGE IV
STAGE I
STAGE II
SETTLED SOLIDS

DOWNSTREAM CONSTRUCTION


SLURRY DISCHARGED AT EMBANKMENT
℄ DAM
SETTLING POOL
STAGE III
STAGE II
SETTLED SOLIDS
STAGE I

CENTERLINE CONSTRUCTION

Figure 23. Methods for raising slurry pond embankments.

gal/min) of relatively chemically pure water seep through the refuse embankment, producing highly contaminated water which requires expensive treatment in order to meet present water discharge requirements. Once a leak through an embankment occurs, it is generally difficult to stop. Provisions are normally made to protect the structural integrity of the embankment by the use of drains and stability beams. The amount of leakage, however, usually is not stopped--it is just controlled. If this situation develops during the operating life of the pond and is remedied by treating the seepage waters, the question then arises as to what happens when the facility is abandoned. It is reasonable to expect the seepage quantity to be reduced but not necessarily eliminated. The chemical quality of these seepage waters may even deteriorate further, and the care or treatment of these seepage waters after abandonment would then become a semipermanent concern, in the same manner as acid mine drainage. At sites which do not have acid-producing refuse, seepage water through the refuse dumps normally meets present water quality standards and may safely be discharged to public streams.

All water-retention embankments leak. At a few sites the embankments are so tight and the seepage is so minor that the seeping water evaporates when it reaches the outer slope. At other sites seepage through the retention embankment may represent a significant portion of the water that is injected into the pond.

The risk of leakage through acid-producing refuse embankments is a continuing concern. However, there are several methods for building slurry impounding embankments of acid-producing coarse refuse. These include using a zoned embankment such as that shown on Figure 24. Here the thin, upstream, nonacid-producing clay zone forms a water barrier. Any water that seeps through this zone is safely drained away through the permeable chimney, horizontal, and abutment drain zones. The acid-producing refuse, which comprises the majority of the dam, is completely isolated from seeping waters from the pond. Another method is to control the gradation of soft shale refuse so that it has a very low permeability. This could be accomplished by mixing fines with the coarse refuse or by mechanically degrading the refuse with special compaction equipment or industrial-type disks to create additional fines.

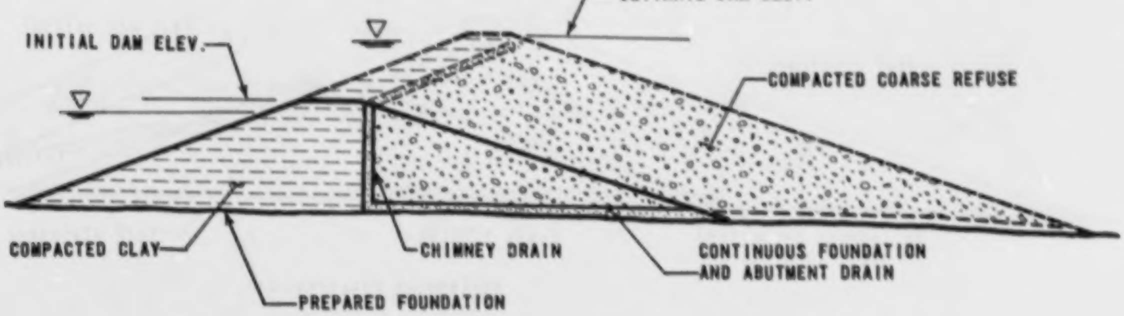


Figure 24. Zoned dam section, showing water barrier formed by clay zone.

The first method is the most reliable for embankment stability and pollution control. However, it may be very costly in parts of Appalachia because of the scarcity of suitable drain material. The second method will help reduce the amount of seepage through the refuse. Fresh refuse from the preparation plant is normally a permeable material. It is only through degradation by exposure to air and water and by mechanical handling that sufficient fines are created to significantly reduce permeability. The amount of fines created varies with material exposure time, weather conditions, handling equipment, etc. More positive controls on permeability are required if the material is to be used as a water barrier.

Perhaps the most environmentally reliable method of constructing slurry pond embankments is to avoid the use of acid-producing refuse in the embankment. Then, if a leak does occur, it can be controlled with suitable graded filters and allowed to drain to receiving streams without significant adverse water pollution.

POND INSPECTION AND MAINTENANCE

Under present MSHA regulations, slurry ponds must be inspected weekly for safety reasons. As a part of this inspection, or in a separate inspection, pollution control observations should also be made. Activities which are required include:

a. Observation and control of the delta formed below the slurry discharge point.

b. Observation of clear-water decant or water return facilities. Particular attention should be given to detecting and repairing any leaks in the slurry pipeline.

c. Observation and control of the operating pool elevation

d. Observation and maintenance of ditches

e. Water sampling and testing of any waters leaving the site

f. Determination of the quantity and quality of seepage waters (seepage survey)

g. Observation and repair of erosion gullies on retaining embankments.

PRINCIPAL GUIDELINES FOR SLURRY POND CONSTRUCTION AND OPERATION

- Whenever possible, slurry pond waters should be recycled to the preparation plant. Open-water circuits should be avoided.

- Sites where there are large drainage areas above the slurry pond should be avoided or should have special provisions to control the effects of incoming storm waters.

- Slurry pond operations should maximize the free-water distance between the slurry discharge point and the clear-water decant structure.

- Fine refuse reclaimed periodically from temporary ponds should be placed in confined, nonstructural areas of the refuse pile.

- The use of acid-producing coarse refuse in impounding embankments should be avoided unless special precautions are taken to minimize or eliminate acidic seepage.

SECTION 9

GUIDELINES FOR RECLAMATION AND ABANDONMENT

Slurry pond or refuse pile abandonment and reclamation activities determine in large part how much pollution will be released to the environment on a permanent or long-term basis. Specific requirements and procedures for abandonment and pollution control depend on federal and local regulations, individual site and material conditions, and the end use planned for the facility. The most common abandonment and reclamation requirements are drainage and erosion control, covering the exposed refuse surfaces with a layer of natural soil, and establishing a vegetative growth. The object of these activities is to return the land to productive use and to eliminate potential environmental pollution.

REFUSE PILES

Reclamation of refuse piles should be an integral part of the ongoing development of the facility. It should not be started only after refuse placement has stopped. Section 7 contains a discussion of various schemes which allow reclamation to proceed simultaneously with development of refuse piles.

Earth Cover Layer

Refuse pile reclamation almost invariably involves covering the finished refuse surface with a layer of nontoxic soil in order to establish plant growth and control erosion. Also, the earth cover layer can effectively eliminate chemical contamination of surface waters moving over acid-producing refuse and can reduce infiltration of surface water into the interior of the refuse mass. Because of the harsh chemical character of refuse and its low plant nutrient value, and because its dark color leads to high surface temperatures, it is very difficult to establish a vegetative growth directly on coarse refuse.

The thickness of the soil cover required for abandoned refuse piles varies with state regulations. The following list indicates some of the many state regulations on soil covering for abandoned acid-producing refuse areas at surface mines.

State	Minimum Cover over Acid-Producing Refuse Areas Centimeters	 Feet	Remarks
Arkanasas	91	3	--
Colorado	61	2	Or 122 cm (4 ft) of water at all times
Illinois	122	4	May be soil or water. Slurry to be confined in depressions and allowed to revegetate naturally.
Indiana	61	2	Soil or water
Iowa	61	2	Coal wastes buried in pits and stabilized. May also be covered with water.
Kansas	61	2	All refuse to be buried
Kentucky		-	Not specific
Maryland	61	2	--
Missouri	122	4	Or permanent water impoundment
Montana	--	-	Not specific
New Mexico	--	-	Not specific
North Dakota	--	-	Not specific
Ohio	--	-	Not specific
Oklahoma	91	3	Or covered with permanent water
Pennsylvania	305 cm (10 ft) clean fill +30 cm (1 ft) topsoil		Alternate 76 cm (30 in.) acid layers with 61 cm (24 in.) clean fill in refuse pile. Bottom of pile to have 91 cm (3 ft) of clean fill.
Tennessee	122	4	Cover with spoil
Texas	--	-	Not specific
Virginia	122	4	--
Washington	61	2	--
West Virginia	122	4	--
Wyoming	--	-	Not specific

Source: Reference 23.

The amount of soil cover required for abandoning a refuse area has a significant effect on reclamation costs. If too little cover is specified, long-term pollution problems could result, but if too thick a cover is specified, the costs are unnecessarily high. In many cases the thickness of the covering layer is determined by the type of vegetation the land is to support. For example, reclaimed land to support row crops requires a thicker soil cover than land to be used for pasture. For pollution control, we believe, the thickness of a cover layer should be based on whether the refuse is acid-producing and on the permeability of the underlying refuse material. If the refuse is nonacid-producing, the quality of runoff or seepage waters is usually within present water quality regulations for point source discharges, and the cover layer need only be thick enough to support the desired vegetation. Increasing cover layer thickness beyond this point will not necessarily increase erosion resistance.

If the refuse is acid-producing, infiltration of surface water into the refuse mass becomes a major consideration. If a clay-type cover layer is perfectly intact and properly sloped, it can be relatively thin and little infiltration will occur. The problem is that thin soil cover layers never form perfect seals. They are constantly exposed to weather changes (freeze-thaw, wet-dry), mechanical demage (plowing, vehicular traffic, animal tracks, minor erosion), and plant root activity. All these factors tend to reduce the effectiveness of thin cover layers in minimizing surface water infiltration. If the underlying refuse material is acid-producing and permeable, the long-term water pollution potential can be significant. If the refuse is relatively impermeable for a reasonable distance below the zone of natural or man-made disturbance, infiltration into the refuse material is minimized. (Methods for making coarse refuse less permeable were discussed in Section 7.)

For abandoned refuse piles that support conventional pasture-type vegetation, the controlling surface disturbance factor is often maximum frost penetration. Eastern U.S. coal-producing regions have recorded frost penetrations ranging from 25 cm (10 in.) to 127 cm (50 in.). The relatively impermeable material should extend about 61 cm (2 ft) below the zone of maximum disturbance.

In summary, abandoned refuse piles should be covered with a layer of non-toxic clay soil of sufficient thickness to promote acceptable vegetative growth. Also, there should be a relatively impermeable zone of natural soil or refuse material under flat-lying areas, extending 61 cm (2 ft) below the maximum depth of frost penetration. The first requirement is directed at preventing pollution of runoff waters and the second requirement at preventing pollution of ground or seepage waters. For nonacid-producing refuse piles, the second requirement would not apply.

Erosion Control

The control of erosion from refuse piles is a major concern. Erosion control requirements are generally more stringent for reclamation and abandonment than for active pile operation. The reason for this is that, during active operations, ditches and related facilities can readily be maintained, but after abandonment, maintenance of erosion control facilities is usually more difficult to initiate because equipment is not immediately available. Consequently, erosion control measures undertaken during abandonment must be of a permanent nature and must call for a minimum of maintenance. For example, perimeter ditches on steep, unstable hillsides around a valley-fill deposit may be acceptable during the operating life of the pile, but they should not be relied on after abandonment, because they normally require considerable maintenance. Whenever possible, permanent diversion ditches above a refuse area should be avoided. If this is not possible, as for example with a side-hill refuse pile, the diversion and drainage ditch should be designed and constructed to achieve minimum long-term maintenance. On waste-heap piles, surface waters must be collected and at some point brought down the side slopes. The ditch leading down the slopes of the pile should be kept on a minimum grade and should have an erosion-resistant facing such as riprap, concrete, or commercially available half-pipes.

Finished surface slopes on top of the pile should always be directed away from the side slopes; otherwise serious erosion could result. The surface slopes should be graded as flat as possible to minimize erosion, but with sufficient grade to drain the runoff without shallow ponding of water.

Providing erosion protection for the finished side slopes of a refuse pile is another important consideration. As mentioned previously, surface drainage should always be directed away from side slopes. The type of vegetative cover established on side slopes is also important, because a higher degree of erosion resistance is required on these steep slopes. The use of a grass mixture which includes crown vetch is becoming quite popular. This type of grass develops a thick mat of spreading, intertwining stems and roots which is highly resistant to erosion. Because crown vetch takes some time to become established, other, more rapidly developing grasses are commonly included in the mix to provide short-term erosion control and protection. Care should be taken in selecting the final grade of side slopes. If the slope is too steep, it may prove difficult or impractical to work on it to cover it with earth, establish plant growth, and provide maintenance. Therefore slopes steeper than about 2 horizontal to 1 vertical should be avoided, as this is about the steepest slope on which tracked bulldozers can operate effectively. Flatter slopes may be required for stability reasons, depending on conditions at the site.

SLURRY PONDS

Slurry pond reclamation normally is not undertaken until the site is abandoned. Prior to abandonment of a slurry pond, it is important to sluice the fine refuse in a manner that will result in a reasonably flat surface with a gentle gradient toward the overflow structure which protects the retention dam. Low areas or dead spots within the pond must be filled so that when the pool is removed the surface of the settled solids will have positive drainage. This is usually accomplished by periodically relocating the slurry discharge point around the perimeter pond.

When the slurry pond is to be abandoned the free water is treated, if necessary, and discharged to downstream receiving streams. If conditions permit, the free water may be allowed to evaporate or may be disposed of by other acceptable means. After the free water is removed the surface of the refuse must be allowed to dry out enough that it may be covered with earth. During the drying period the surface of the silty, fine refuse develops an upper crust which is highly susceptible to wind erosion. In high winds, large, thick, dust clouds may then blow off unprotected, abandoned slurry ponds. If a thick, permanent plant growth can be established directly on the refuse this condition can be alleviated, but in most cases this cannot readily be accomplished and a layer of vegetation-supporting soil is required.

Covering a recently abandoned slurry pond may call for special construction techniques. Beneath the thin surface crust of dried refuse the material can be saturated and highly unstable. This is particularly true of areas near clear-water decant or pump return structures where the finer portions of solids have settled out. Hauling equipment usually cannot travel directly over the surface of these areas because the ground is too soft. Conventional practice calls for the use of light equipment, and for pushing a fill out ahead of the equipment to serve as a working pad. The thickness of this pad can be quite large in the lower portions of the pond area.

The thickness of the earth cover layer should be the minimum necessary to support the desired vegetation. Providing a reliable and impermeable cover of clay, as suggested for acid-producing refuse piles, would not normally be required for slurry ponds, since the refuse lies in a closed basin. Also, the permeability of fine refuse is generally much lower than that of coarse refuse.

The reclamation plan should include provisions for plugging with concrete any decant or overflow pipes that are located beneath retaining dams or dikes. Permanent drainage out of the abandoned pond should be provided for by an erosion-resistant open spillway designed to pass the flood flows specified in the regulations.

MSHA regulations require that slurry ponds be abandoned according to a plan which ensures slope stability and which precludes any future water impoundment.[23] This rule applies to slurry impoundments that are more than 152 cm (5 ft) deep and that provide more than 24,672 cubic meters (20 acre-feet) of water storage or to impoundments that are more than 6 meters (20 ft) deep. An impoundment such as a slurry pond can serve as an effective pollution control device by reducing the amount of suspended solids released to downstream waters. Therefore, consideration should be given to leaving a small sedimentation basin in the pond area provided the water quality of such a pond is acceptable, the basin does not exceed regulation size, and there are no acidic leaks downstream.

For slurry ponds other than diked or incised ponds, permanent drainage or diversion ditches are required. These ditches should be planned with consideration given to the same factors as those mentioned for refuse piles.

SECTION 10

ALTERNATIVE DISPOSAL AND POLLUTION CONTROL METHODS

So far we have discussed primarily the methods for controlling pollution from conventional refuse piles and slurry ponds. There are other disposal methods which are used, however, depending on individual site conditions. These methods include burial in spoil piles of surface mines, underground disposal in mined-out areas of subsurface mines, utilization of refuse as a construction material, and dry disposal of fine coal refuse.

In this section, the general features and relevant pollution control aspects of some of these alternative disposal techniques are discussed.

BURIAL OF REFUSE IN SURFACE MINE SPOIL PILES

Coarse Refuse

Burial of coarse refuse in active surface mine spoil piles is common in the Midwest. Normal procedures include trucking the coarse refuse back to the bottom of the active mine pit and dumping it at the toe of the spoil bank. Special layering or compaction is usually not required. As stripping operations progress, the refuse is covered with relatively great thicknesses of spoil material, thus minimizing the release of pollutants to the environment. If the bottom of the mine pit is below the water table, as is the case at many Midwestern surface mines, the potential for acid production from the refuse is essentially eliminated. Other advantages of this type of arrangement are that the spoil pile eyesore is eliminated, there are no refuse slope stability problems, and land use is more effective.

The only potential pollution concern with this method is the possibility that air and water may infiltrate through the loose spoil and into acid-producing refuse above the water table, releasing chemical pollutants into the ground-water regime. However, this concern is thought to be minor compared to those resulting from some other disposal methods. The thickness of the spoil cover and its generally low permeability indicate that any release of chemical pollutants to the ground water would be relatively small.

Slurry Ponds

At some Midwestern surface mines, slurry ponds have been developed between successive rows of old spoil banks or in the last furrow of a surface mine cycle. The principal pollution control concern in these cases is that large amounts of water could seep from the pond into the loose, semipermeable spoil banks and thus pollute ground water. Seepage waters not only contain dissolved solids from the slurry pond but may also pick up large concentrations of salts from the spoil material. At one active surface mine where a slurry pond was constructed in contact with mine spoil, seepage waters entering the active mine pit created slope stability problems along the spoil side of the pit and also created difficulties in attempting to dewater the pit. The water entering the pit had a high concentration of dissolved solids, mainly due to leaching in the spoil banks, and would not meet discharge water quality requirements.

Placing of slurry ponds or any type of water impoundment on mine spoil should be avoided. If this is not economically feasible--and at many large surface mines it is not--the use of sealed ponds should be considered, and special ground-water investigations may be desirable to identify potential pollution problems and to develop solutions.

UNDERGROUND DISPOSAL

Disposing of coal refuse underground, in mined-out coal seams, is an environmentally attractive disposal method in certain circumstances, and such systems have received considerable attention in the United States and Europe. The principal advantages of this method are that hazardous and unattractive surface refuse piles and ponds are eliminated, ground subsidence over mined areas is reduced, and less surface pollution is created. The principal disadvantages are cost, the potential for ground-water pollution, and health and safety problems for mine workers engaged in backfilling operations in active mines.

In the United States, underground disposal of coal refuse is used primarily to control subsidence in abandoned mine workings under developed residential and commercial areas. In a report to the National Science Foundation, a study commission concluded:

> In general the economic costs of underground disposal exceed by far the normal costs of surface disposal. Only if the physical conditions at a mine site for enviornmentally acceptable surface disposal were so adverse or the social benefits of underground disposal so great would underground disposal become economically competitive with surface disposal for modern, high production rate coal mines.[24]

In pollution control, the principal concern in using underground refuse disposal is its effect on ground water. Storage of acid-producing refuse in mines where both air and water are available can lead to increased acid mine drainage. Coarse refuse injected in a mine usually has significantly greater air and water permeability than coarse refuse deposited in a properly constructed surface facility. Detailed ground-water studies and expert opinion are recommended in cases where underground disposal above the water table is contemplated.

USE OF REFUSE AS CONSTRUCTION MATERIAL

Various ways of using coarse refuse have been tried in past years in attempts to turn an economic liability into an economic asset. Some of these uses include refuse as a construction fill, as a lightweight aggregate, as roadbase and antiskid materials, or as a brickmaking material. Of these, only its use as construction fill has had a significant success. Fills constructed of refuse have been used for paved roads, dams, and area fills. The most promising construction use is as an area fill in the steep, mountainous regions of Appalachia where flat, usable land is at a premium. Properly constructed and reclaimed, a disposal area can be utilized for residential or light commercial buildings, playgrounds, cemeteries, etc. The potential or refuse as a structural fill is dependent on embankment quality and on operators' ingenuity and local needs. Several new refuse operations have been started with specific end uses, other than agricultural, in mind. The trend toward constructing usable refuse fills is likely to continue.

Pollution control concerns with respect to utilization of refuse for construction fills depends in large part on the end use. If acid-producing refuse is used, a major consideration is the potential for acid drainage. Each situation should be evaluated on an individual basis. For example, a recreational lake on an unsealed acid-producing refuse pile would not be considered a good end use unless the entire refuse pile could be submerged. On the other hand, a large, flat refuse pile, properly covered with natural soil and vegetation, would probably be an excellent location for a football field, a baseball diamond, or similar type of recreational facility.

DRY DISPOSAL OF FINE COAL REFUSE

Instead of disposing of fine coal refuse in slurry form behind a retention dam, it is possible to dewater the slurry at the preparation plant and to dispose of the fine refuse in a dry landfill in a manner similar to coarse refuse disposal. As outlined by Nunenkamp,[12] the operation involves the following steps:

1. Clarification - slurry with a low percentage of solids is put through a thickener tank to concentrate the solids into a thickener underflow.

2. Mechanical Dewatering - thickener underflow containing about 30% solids is mechanically dewatered using filters, centrifuges, high-speed screens, or similar devices. In most cases the resulting solids contain a high percentage of moisture and are hard to handle. Because the solids are in a semifluid state there may be spillage problems on haul roads in the disposal area. Heavy equipment is unable to maneuver over the material and an attempt to mix coarse refuse with this material can render the entire refuse pile unstable. Segregated disposal is also awkward because the area containing the fine refuse material must be allowed to air-dry sufficiently to support hauling and placing equipment. Because of this problem, further dewatering may be necessary.

3. Thermal Drying - the numerous approaches to dewatering refuse tailings by thermal methods all require technical and economic assessment on a case-by-case basis. Both direct heat and indirect heat contact systems have been studied experimentally. It is generally considered that neither the direct nor the indirect drying system has a strong potential for dewatering fine refuse slurry, as both processes give a product that, though dry, still

lacks desirable characteristics for subsequent handling and final disposal. Such systems also add a large capital and operating cost for a secondary thermal dryer and particulate recovery system. However, some thermal dewatering systems are available that do not merely dry the material. These systems are the fluid-bed calcining agglomerator and the multiple-hearth incinerator. Pilot-plant tests have indicated that when a mechanically dewatered refuse slurry of 35% to 45% moisture is placed in a multiple-hearth incinerator and ignited, it can consume itself and generate enough heat to preheat and ignite the incoming feed.

The major deterrent to the widespread use of slurry dewatering is cost. From a pollution control standpoint, the methods used for slurry dewatering may in fact result in greater air and water pollution than does the use of slurry ponds, because of stack gas emissions from thermal dryers and erosion and sedimentation from storm waters passing over the exposed, highly erodable, fine refuse placed in the disposal area, or because additional acid-producing refuse is exposed to air and water in the disposal area.

Pollution control guidelines for constructing refuse piles that have fine refuse as the principal waste component are different from guidelines for refuse piles constructed of coarse refuse, because the physical properties of the two types of refuse are significantly different. The major pollution concerns are:

1. Erosion - fine refuse is highly erodable and exposed slopes must be protected with a resistant covering.

2. Dust - exposed refuse dries on the surface to a powderlike consistency. Winds and equipment traffic raise the material from the pile in large, thick clouds of airborne particulates.

3. Refuse Strength - under many conditions where water is present, fine refuse has less strength than coarse refuse. It must be compacted in thin lifts (less than 30 cm) and at carefully controlled moisture contents (compaction of fine refuse depends very strongly on moisture content). As a fill, fine refuse (sandy silt) is one of the most difficult of all materials to manage.

In conclusion, it appears that presently available methods for effectively dewatering and disposing of fine refuse in dry disposal areas are very costly, and possibly are more environmentally harmful than properly constructed and operated slurry ponds. Where dewatering and dry disposal of fine refuse are required because no suitable slurry pond site is available, special pollution control measures are needed. These measures should be defined on a site-specific basis.

REFERENCES

1. W. A. Wahler & Associates. "Coal Mine Refuse Disposal Practices and Technology," USBM Contract S0122084, Mining Enforcement and Safety Administration, U.S. Department of the Interior, February 1974.

2. D'Appolonia Consulting Engineers, Inc. "Engineering and Design Manual, Coal Refuse Disposal Facilities," for Mining Enforcement and Safety Administration, U.S. Department of the Interior, undated.

3. National Coal Board of England. "Spoil Heaps and Lagoons," 1970.

4. U.S. Mining Enforcement and Safety Administration. "Design Guidelines for Coal Refuse Piles and Water, Sediment, or Slurry Impoundments and Impounding Structures," April 16, 1976.

5. Moulton, L. K. et al. "Coal Mine Refuse: An Engineered Material," in: Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal, National Coal Association, October 1974. pp. 1-25.

6. U.S. Department of the Navy. "Design Manual: Soil Mechanics, Foundations, and Earth Structures," NAVFAC DM-7, March 1971.

7. Davidson, W. H. "Reclaiming Refuse Banks from Underground Bituminous Mines in Pennsylvania," in: Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal, National Coal Association, October 1974. pp. 186 - 199.

8. Martin, J. F. "Quality of Effluents from Coal Refuse Piles," in: Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal, National Coal Association, October 1974. pp. 26 - 37.

9. Caruccio, F. T. "The Quantification of Reactive Pyrite by Grain Size Distribution," in: Proceedings of the Third Symposium on Coal Mine Drainage Research, May 1970. pp. 123 - 131.

10. Haynes, R. J. and W. D. Klimstra. "Some Properties of Coal Spoilbank and Refuse Materials Resulting from Surface Mining Coal in Illinois," Institute for Environmental Quality, State of Illinois, October 1975.

11. Hill, R. D. "Water Pollution from Coal Mines," presented at: Forty-Fifth Annual Conference of the Water Pollution Control Association of Pennsylvania, 1973.

12. Nunenkamp, D. C. "Coal Preparation Environmental Engineering Manual," U.S. Environmental Protection Agency, May 1976.

13. Woodward-Clyde Consultants. "Research and Development Program on the Disposal of Retorted Oil Shale: Paraho Oil Shale Project," PB-253-598, U.S. Bureau of Mines, July 1975.

14. _______________. "Belt Drives Fill for Earth Dam," Engineering News-Record, December 3, 1942.

15. _______________. "Conveyor Moves Fill down a Mountain," Construction Methods and Equipment, November 1958. p. 84.

16. Bennett, P. T. "Materials and Compaction Methods: Missouri Basin Dams," Report 95, Question 22, Sixth Congress on Large Dams, New York, 1958.

17. Lane, K. S. and R. G. Fehrman. "Tuttle Creek: A Dam of Rolled Shale and Dredged Sand," presented at: Convention of the American Society of Civil Engineers, Reno, Nevada, June 1960.

18. _______________. "Triple-Threat Rigs at Briones Dam," Western Construction, February 1963. p. 58.

19. Sherard, J. L. et al. Earth and Earth-Rock Dams, John Wiley and Sons, New York, 1963.

20. Sawyer, S. G. and J. W. Fredland. "Experience in Field and Laboratory Compaction Testing of Coarse Coal Mine Waste," presented at: Second Symposium on Coal Preparation, October 1976.

21. _______________. "Million-Dollar Refuse Disposal System," Coal Mining and Processing, December 1976. pp. 80 - 82.

22. Hill, R. D. "Sedimentation Ponds: A Critical Review," in: Proceedings of the Sixth Symposium on Coal Mine Drainage Research, October 1976. pp. 190 - 199.

23. U.S. Department of the Interior. "Laws and Regulations Affecting Coal," June 1976.

24. National Academy of Sciences. "Underground Disposal of Coal Mine Wastes," Washington, D.C., 1975.

APPENDIX A

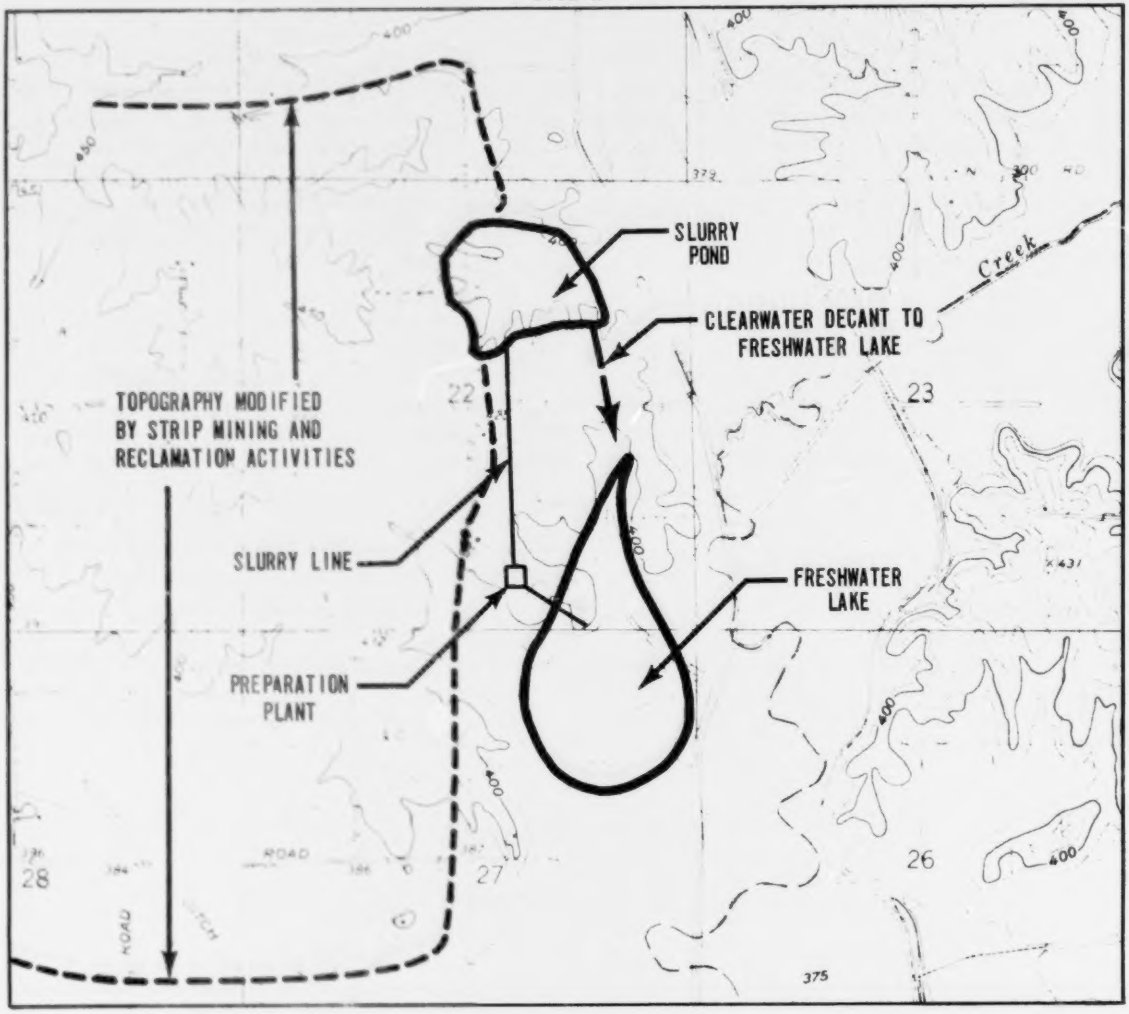
RESULTS OF SITE INVESTIGATIONS AND SAMPLING PROGRAMS

This appendix presents the detailed results of the site investigations and water and air quality sampling programs. For each site, pertinent hydrologic data and descriptions of site features and operations are given, together with tables presenting the measurement data obtained in the sampling programs.

Averaged data showing increases or decreases in water pollutant concentrations are presented only for Sites A through E, because these were the only sites sampled where unique points could be identified both for water entering a disposal area and for water leaving the disposal area. No air quality measurements were made at Site A, because it consists only of a slurry impoundment with no dry-land refuse pile and the air quality sampling program was concerned only with emissions from refuse piles.

No water or air quality sampling was carried out at Site I, which is not exclusively a coal refuse disposal site. Instead, it is an impoundment designed, developed, and operated by an electric utility company primarily for disposal of flyash from nearby generating plants. The utility is permitting a coal mining company to dispose of refuse at this site in order to raise the main embankment of the impoundment dam. Site I was included in the visits primarily to investigate the special pollution control methods required in this unusual disposal situation, and also to document an outstanding example of cooperation between two types of enterprises to achieve environmentally acceptable refuse disposal in a manner that has benefits for both companies.

SITE A


SLURRY POND
CLEARWATER DECANT TO FRESHWATER LAKE
TOPOGRAPHY MODIFIED BY STRIP MINING AND RECLAMATION ACTIVITIES
SLURRY LINE
PREPARATION PLANT
FRESHWATER LAKE
Creek
ROAD
22
23
26
27
28
400
375

HYDROLOGIC DATA

Drainage Area:	32 ha (78 acres)
Precipitation (mean annual):	107 cm (42 in.)
Pond Evaporation (average annual):	89 cm (35 in.)
Temperature Extremes (Jan-July):	Mean max. 6°C(43°F) to 32°C (89°F) Mean min. -3°C (26°F) to 26°C (78°F)
Rainfall Design Frequencies:	(24-hour storms)

	5-yr	10-yr	50-yr	100-yr
Depth, cm (in.)	10.7(4.2)	11.9(4.7)	15.2(6.0)	16.51(6.5)
Max. Storm Water Volume, m^3x10^3 (acre-ft)	33(27)	38(31)	48(39)	52(42)

SITE A: FEATURES AND OPERATIONS

Site A is in typically Midwestern flatlands. The impoundment is a cross-valley facility constructed across a small, unnamed tributary of a nearby creek. The topography to the immediate west of the site has been modified by surface mining and land reclamation activities. The modified drainage area above the pond is very small—less than 2.023 ha (5 acres)—and is composed of reclaimed mine spoils. A creek approximately 152.4 m (500 ft) downstream of the impoundment generally flows year around and during heavy rains has been reported to back up water to or near the toe of the embankment.

The embankment retaining the slurry pond was constructed in 1971 using natural clayey soils placed in thin lifts and compacted with sheepsfoot rollers. The downstream slopes were aerially seeded with fescue, alfalfa, clover, and bluegrass. The upstream slope, above the water line, was later riprapped with limestone in those areas where wave action was causing erosion problems. The crest of the embankment is used as a coal haulage road and is traversed by 164 Mt (180-ton) trucks.

Slurry is pumped into the upper portion of the impoundment at approximately 13.25 m^3pm (3,500 gpm). At the lower end of the pond clear water is decanted by gravity into a 32.4 ha (80-acre) freshwater lake located 0.805 km (one-half mile) to the south. Pumps at the lake recirculate the water back to the coal preparation plant. This site has an NPDES discharge point (#001) at a vertical drop outlet in the lake. This is monitored weekly and water samples are analyzed when discharge occurs. Any makeup water requirements are obtained from the creek.

DIMENSIONAL DATA

Retaining Embankment	
Crest width	22.56 m (74 ft)
U/S slope	(2:1)
D/S slope	(3:1)
Max. vert. distance to foundation	12.19 m (40 ft)
Spillway	2-24" C.M.P.s

Retention Area	
Maximum storage pond area	29.5 ha (73 acres)
Normal storage pond area	29.5 ha (73 acres)
Ultimate storage volume	2,159,000 m^3 (1,750 acre-ft)
Freeboard	1.52 m (5 ft)
Total drainage area	31.6 ha (78 acres)

TYPE OF REFUSE AND PRIOR PROCESSING

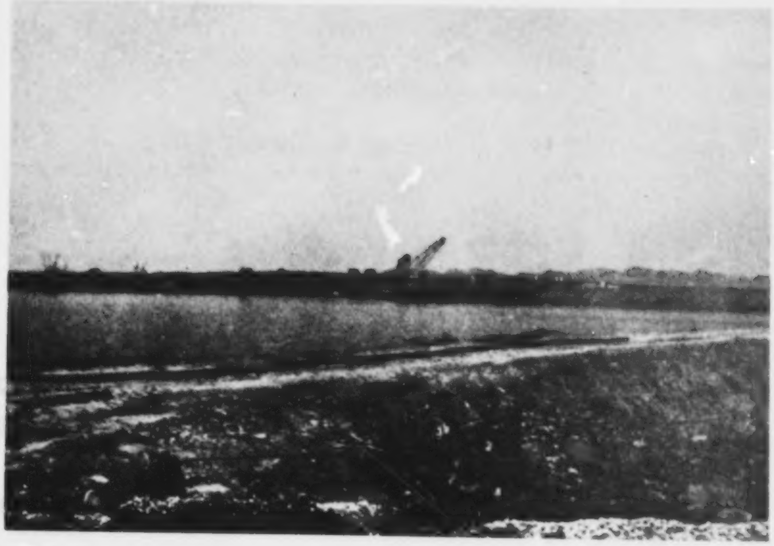
The two coal seams surface-mined at the site are vertically separated by an interbed of shale and/or limestone that varies between 1 m (3 ft) and 1.3 m (4 ft) in thickness. The shale/limestone refuse is returned to the mine cut during the mining process. All other run-of-the-mine material is brought to the preparation plant, separated on a 15 cm (6-in.) screen, and processed using jig wash boxes. Of the 11,350 Mt/d (12,500 tpd) thus processed, approximately 19% is rejected: 5 % in fine refuse, which is routed to the slurry pond, and 14% in coarse refuse, which is returned to the active surface mine pit for use as deep fill. Thus, the average production of the mine is 9,100 Mt/d (10,000 tpd) of clean steam coal. The reported average chemical quality of the washed coal is as follows:

Moisture	13.12%
Volatiles	33.35%
Ash	9.63%
Fixed Carbon	43.90%
Sulfur	3.34%
Heat Content	11,020 Btu

POLLUTION CONTROL CONSIDERATIONS

- The preparation plant recirculates slurry pond waters.
- The minor seepage from the toe of the dikes, which is typical of a well-designed and -constructed embankment, is nonacid and reports to the fresh-water reservoir.
- A creek, located immediately downstream and approximately parallel to the dikes, provides an excellent water sampling station for determining the influence of the slurry pond on public streams.
- The dikes are covered first with native clayey soils, and soon become vegetated. The upstream surfaces are riprapped with coarse rock to minimize wave action erosion.

CREST OF DAM (74 FT. WIDE AT THIS POINT), WITH SLURRY POND TO RIGHT. IN THE BACKGROUND ARE THE PREPARATION PLANT AND STORAGE SILOS.



GENERAL VIEW OF SLURRY POND, WITH 150 CU. YD. DRAGLINE IN THE BACKGROUND.

EXPOSED FINE REFUSE IN UPPER PORTION OF SLURRY POND. EARTH MOUND AT RIGHT CENTER WAS BUILT TO REDIRECT SLURRY INTO DEAD SECTIONS OF THE POND AND THUS INCREASE POND SETTLING EFFICIENCY.

NORTHERN DOWNSTREAM SLOPE OF EARTH RETAINING EMBANKMENT (LEFT). EXCELLENT GRASS COVERING PROVIDES EROSION CONTROL. THE LIGHT COLORED SLOPES (UPPER RIGHT) ARE UNRECLAIMED MINE SPOIL.

TABLE A-1. SUMMARY OF WATER QUALITY DATA: SITE A
(Averages for four site visits)

	Sampling Point			Increase (+) or Decrease (-) between Inlet and Outlet Points
	1 (Inlet)[a]	2[b]	3 (Outlet)[c]	
Parameter				
Flow (liters/min)	17 - 33	17 - 33	17 - 33	--
pH	7.88	8.08	8.00	+0.12
Dissolved O_2 (mg/liter)	7.15	7.50	7.0	-0.15
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	201	211	204	+3
Conductivity (umhos/cm)	2,433	2,488	2,423	-10
Pollutant (mg/liter)				
Aluminum	0.84	1.20	1.16	+0.32
Cadmium	0.003	0.004	0.003	--
Chloride	80	76	72	-8
Copper	0.005	0.004	0.004	-0.001
Ferrous iron	0.08	0.08	0.11	+0.03
Total iron	1.04	1.30	1.48	+0.44
Lead	0.016	0.009	0.009	-0.007
Magnesium	155	156	159	+4
Manganese	1.16	1.21	1.23	+0.07
Mercury	<0.0001	<0.0001	<0.0001	--
Nickel	0.012	0.015	0.013	+0.001
Sulfate	1,275	1,415	1,350	+75
Zinc	0.02	0.02	0.03	+0.01

---

a. Upstream from slurry pond.

b. Approximate midpoint on perimeter of site.

c. Near edge of property, where creek exits site.

TABLE A-2. WATER QUALITY DATA: SITE A, SAMPLING POINT 1[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liters/min)	13.5	17 - 29	Frozen	20 - 37
pH	7.45	8.15	7.80	8.10
Dissolved O_2 (mg/liter)	7.15	--	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	166	215	262	162
Conductivity (umhos/cm)	2,160	2.270	3,200	2,100
Pollutant (mg/liter)				
Aluminum	1.3	0.67	0.38	1.0
Cadmium	<0.001	--	0.001	0.006
Chloride	39	149	52	78
Copper	0.002	--	0.011	0.002
Ferrous iron	0.1	0.1	0.03	0.08
Total iron	1.45	0.98	0.34	1.7
Lead	0.012	--	0.001	0.034
Magnesium	112	137	240	130
Manganese	0.83	0.49	2.6	0.72
Mercury	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	<0.001	--	0.027	0.009
Sulfate	1,000	1,200	1,700	1,200
Zinc	0.01	0.02	0.04	0.02

---

a. Upstream from slurry pond.

TABLE A-3. WATER QUALITY DATA: SITE A, SAMPLING POINT 2[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liters/min)	13.5	17 - 29	Frozen	20 - 37
pH	8.20	8.30	7.70	8.10
Dissolved O_2 (mg/liter)	7.50	--	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	190	210	262	180
Conductivity (umhos/cm)	2,160	2,390	3,200	2,200
Pollutant (mg/liter)				
Aluminum	2.0	0.77	0.94	1.1
Cadmium	<0.001	--	0.006	0.006
Chloride	45	148	56	55
Copper	0.001	--	0.008	0.002
Ferrous iron	0.1	0.10	0.04	0.06
Total iron	1.83	1.24	0.33	1.80
Lead	0.005	--	0.003	0.018
Magnesium	113	132	240	140
Manganese	0.96	0.49	2.6	0.80
Mercury	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.005	--	0.030	0.009
Sulfate	960	1,300	2,000	1,400
Zinc	0.01	0.02	0.04	0.02

---

a. Sampling point at approximate midpoint on perimeter of site.

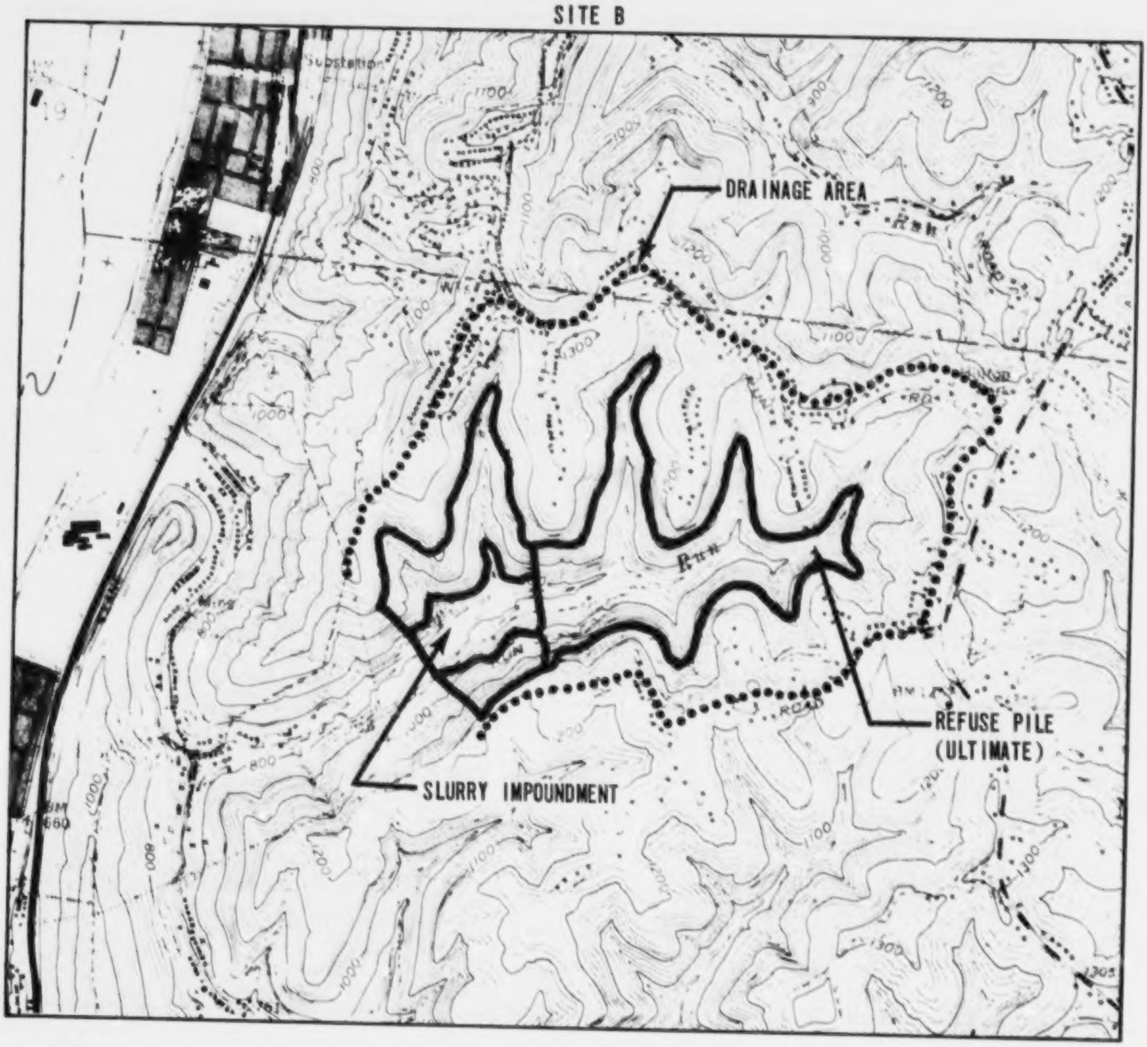
TABLE A.4 WATER QUALITY DATA: SITE A, SAMPLING POINT 3[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	13.5	17 - 29	Frozen	20 - 37
pH	8.00	8.10	7.75	8.10
Dissolved O_2 (mg/liter)	7.00	--	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	185	200	249	180
Conductivity (umhos/cm)	2,190	2,400	2,900	2,200
Pollutant (mg/liter)				
Aluminum	1.4	1.2	0.94	1.1
Cadmium	<0.001	--	0.006	0.006
Chloride	35	141	57	55
Copper	0.001	--	0.008	0.002
Ferrous iron	0.1	0.26	0.01	0.06
Total iron	1.78	2.02	0.33	1.8
Lead	0.006	--	0.003	0.018
Magnesium	119	135	240	140
Manganese	0.83	0.70	2.60	0.80
Mercury	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	<0.001	--	0.030	0.009
Sulfate	1,000	1,200	1,800	1,400
Zinc	0.02	0.02	0.04	0.02

---

a. Near edge of property, where creek exits site.

SITE B


DRAINAGE AREA
REFUSE PILE (ULTIMATE)
SLURRY IMPOUNDMENT
Substation
Run
Run
ROAD
RD
BM 680
800
1000
1100
1200
1300

HYDROLOGIC DATA

Drainage Area	220 ha (540 acres)
Precipitation (mean annual):	102 cm (40 in.)
Pond Evaporation (average annual):	76 cm (30 in.)
Temperature Extremes (Jan-July):	Mean max. 6°C (42°F) to 31°C (88°F) Mean min. -4°C (24°F) to 17°C (62°F)
Rainfall Design Frequencies:	(24-hour storms)

	5-yr	10-yr	50-yr	100-yr
Depth, cm (in.)	8.4(3.3)	9.9(3.9)	12.2(4.8)	13.2(5.2)
Est. Storm Water Volume, $m^3 \times 10^3$ (acre-ft)	185(150)	222(180)	274(220)	296(240)

SITE B: FEATURES AND OPERATIONS

Site B is located in a steep, narrow hollow which has occasional springs along the valley slopes. The site is in mountainous terrain and has a maximum relief of 137 m (450 ft). The refuse area is a valley-fill type disposal facility which was started in 1969. Immediately below the present refuse area is a slurry pond which eventually will be covered with refuse.

A perimeter ditch, excavated into the hillside above the refuse, completely surrounds the refuse and discharges the collected waters below the disposal area. The perimeter ditches are continuously maintained to keep them clear of debris and to repair any local landslide conditions. Rainfall on the refuse pile in the immediate vicinity of the impoundment is directed into the slurry impoundment, where it is either allowed to evaporate or is pumped over the dam into the streambed. The slurry impoundment is fitted with a large, concrete spillway to prevent overtopping. Slurry is presently being pumped into the impoundment.

Refuse is taken by conveyor from the preparation plant to a storage bin adjacent to the slurry impoundment. Two Terex scrapers, Model TS24, with a capacity of 18 m^3 (24 yd^3), haul the refuse from the bin to the head of the hollow, where the material is placed in the downstream direction. The specified maximum lift thickness is 31 cm (12 in.); however, the scraper operators prefer to lay the refuse in lifts 15 to 20 cm (6 to 8 in.) thick. The surface of the refuse is to be crowned with a minimum slope of 1 to 1-1/2%. Side slopes are a maximum of 2 (horizontal) to 1 (vertical). A water truck and a D-9 bulldozer are used to maintain the haul roads. The bulldozer is also used to dress the refuse area. A D-8 bulldozer was used for the initial construction of the channels. Restoration of the refuse is primarily accomplished during downtime periods such as when the mine or preparation plant is temporarily out of production; however, this is an ongoing activity and is not limited to downtime. Restoration includes covering all finished refuse surfaces with 30 to 60 cm (1 to 2 ft) of clay soils, and seeding.

DIMENSIONAL DATA

Refuse Area	
Surface area	24-32 ha (60-80 acres)
Drainage area	220 ha (540 acres)
Maximum height	76 m (250 ft)
Finished surface slope	1 to 1½%
Finished side slope	Maximum 2:1

TYPE OF REFUSE AND PRIOR PROCESSING

The coal is mined from a seam located at an average depth of 91 m (300 ft) below ground surface. The coal is high-sulfur steam coal approximately 1.5m (5 ft) thick. In this area, the coal seam has a shale parting up to 46 cm (18 in.) in thickness. Mining operations remove the coal and shale parting, along with the materials later separated in the preparation plant. Continuous and longwall miners are presently used to extract the coal.

The preparation plant uses a combination of froth flotation and heavy media circuits to clean the coal. The coarse refuse is separated with a series of screens at 0.8 cm (0.3 in.). The minus 0.8 cm (0.3 in.) material is mixed with the washed coarse size to obtain a plant product. The run-of-the-mine coal production is approximately 6,370 Mt/d (7,000 tpd), with 15% being coarse reject. The chemistry for the coal produced has been reported as follows:

Moisture	6.08%
Ash	14.21%
Sulfur	4.14%
Heat content	11,780 Btu

POLLUTION CONTROL CONSIDERATIONS

- When the slurry pond is in operation, excess clarified water is decanted into the public streams (open-water circuit).
- Drainage off the acid-producing refuse pile in the upper reaches of the hollow is directed into the slurry pond.
- An interceptor ditch has been cut into the sides of the valley to divert the major portion of incoming waters around the refuse pile.
- The site is in difficult mountainous terrain with numerous springs.
- Landsliding occurs along the steep, heavily wooded valley slopes.
- Restoration (i.e., covering with earth and seeding) is proceeding on finished surfaces of the refuse pile. While restoration goes on at the head of the hollow, refuse placement continues in the downstream direction.
- Stream flows above and below the refuse disposal area allow for water sampling and testing to evaluate pollution control at the refuse area.

Lower end of refuse pile (foreground) slopes into slurry pond (center). White notch cut in center of retaining dam is spillway structure. Along the right abutment of the valley a perimeter ditch diverts drainage and run-off waters away from cleared area.

Closeup of perimeter ditch. These ditches require continual maintenance to keep them clear of debris and silt. Periodic repair of slope failures is also common.

Upper end of refuse pile. Note dust cloud trailing scraper at center. To minimize erosion and potential for landsliding, clearing of vegetation on abutments is limited to that required for immediate working needs.

View from lower end of slurry pond looking towards the refuse pile. Note that drainage off the refuse pile is directed into the slurry pond.

FINISHED REFUSE SURFACE AT HEAD OF RUN. THE SURFACE HERE IS BEING COVERED WITH SOIL AND RECLAIMED. TOPSOIL HAS BEEN PLACED OVER AREA TO THE RIGHT, WHILE LEFT SURFACE IS EXPOSED REFUSE IN FINAL PROCESS OF GRADING.

TABLE A-5. SUMMARY OF WATER QUALITY DATA: SITE B
(Averages for four site visits)

	Sampling Point					Increase (+) or Decrease (-) between Inlet and Outlet Points
	1 (Inlet)[a]	2[b]	3[c]	3A[c]	4 (outlet)[d]	
Parameter						
Flow (liter/min)	7.0	321 - 875	88	--	545	+538
pH	7.9	7.9	7.5	8.0	7.6	-0.3
Dissolved O_2 (mg/liter)	10.6	10.5	9.3	9.3	9.3	-1.3
Acidity (mg/liter as $CaCO_3$)	--	--	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	139	163	335	354	242	+103
Conductivity (umhos/cm)	522	1,153	2,8[illegible]	2,840	2,110	+1,588
Pollutant (mg/liter)						
Aluminum	0.53	0.69	2.33	4.40	1.67	+1.14
Cadmium	0.002	0.002	0.031	--	0.004	+0.002
Chloride	48	112	206	377	187	+139
Copper	0.002	0.007	0.120	--	0.007	+0.005
Ferrous iron	0.06	0.07	0.66	1.90	0.53	+0.47
Total iron	0.77	1.51	27.88	40.00	16.61	+15.84
Lead	0.004	0.003	0.034	--	0.028	+0.024
Magnesium	13	22	67	65	39	+26
Manganese	0.14	0.99	5.05	5.20	2.64	+2.50
Mercury	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	--
Nickel	0.004	0.013	0.028	--	0.026	+0.022
Sulfate	98	590	1,500	1,600	1,023	+925
Zinc	0.03	0.02	0.13	0.24	0.08	+0.05

---

a. Hillside stream above refuse pile.
b. Lower end of diversion ditch along site perimeter.
c. Combined slurry pond seepage and refuse pile drainage.
d. Downstream from confluence of diversion ditch and Sampling Point 3 flow.

TABLE A-6. WATER QUALITY DATA: SITE B, SAMPLING POINT 1[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	12	2	10	4
pH	7.90	8.05	7.85	7.9
Dissolved O_2 (mg/liter)	--	10.6	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	124	145	129	157
Conductivity (umhos/cm)	470	497	440	680
Pollutant (mg/liter)				
Aluminum	0.25	0.21	1.1	0.57
Cadmium	<0.001	--	0.001	0.003
Chloride	--	65	34	44
Copper	0.001	--	0.004	0.001
Ferrous iron	0.1	0.07	0.03	0.04
Total iron	0.18	0.31	1.6	1.0
Lead	0.005	--	0.002	0.006
Magnesium	11.6	13	14	14
Manganese	0.04	0.14	0.23	0.13
Mercury	0.0003	<0.0001	<0.0001	<0.0001
Nickel	0.001	--	0.006	0.006
Sulfate	91	90	100	110
Zinc	<0.01	0.01	0.08	0.01

---

[a] Hillside stream above refuse pile.

TABLE A-7. WATER QUALITY DATA: SITE B, SAMPLING POINT 2[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	750 - 950	120	800	93
pH	6.50	8.50	8.15	8.30
Dissolved O_2 (mg/liter)	--	10.5	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	141	152	205	154
Conductivity (umhos/cm)	1,900	141	970	1,600
Pollutant (mg/liter)				
Aluminum	0.26	0.28	1.9	0.32
Cadmium	<0.001	--	0.001	0.004
Chloride	--	127	100	110
Copper	0.004	--	0.010	0.007
Ferrous iron	0.1	0.01	0.05	0.03
Total iron	0.1	0.21	5.0	0.72
Lead	0.001	--	0.001	0.006
Magnesium	23.5	22	22	21
Manganese	1.11	0.86	1.9	0.07
Mercury	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.013	--	0.014	0.011
Sulfate	760	630	370	600
Zinc	0.01	0.01	0.03	0.01

---

[a] Lower end of diversion ditch along site perimeter.

TABLE A-8. WATER QUALITY DATA: SITE B, SAMPLING POINT 3[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	190	50	20	92
pH	6.70	7.95	7.45	7.90
Dissolved O_2 (mg/liter)	--	9.3	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	275	354	340	362
Conductivity (umhos/cm)	2,800	2,840	2,600	3,300
Pollutant (mg/liter)				
Aluminum	4.4	4.4	0.43	0.09
Cadmium	0.001	--	0.002	0.010
Chloride	--	377	110	130
Copper	0.012	--	0.011	0.012
Ferrous iron	0.4	1.9	0.20	0.14
Total iron	3.5	40.0	37.0	31.0
Lead	0.065	--	0.010	0.027
Magnesium	74	65	64	64
Manganese	5.9	6.2	4.3	3.8
Mercury	0.0003	<0.0001	<0.0001	<0.0001
Nickel	<0.001	--	0.031	0.053
Sulfate	1,500	1,600	1,400	1,500
Zinc	0.21	0.24	0.05	0.03

---

[a] Combined slurry pond seepage and refuse pile drainage.

TABLE A-9. WATER QUALITY DATA: SITE B, SAMPLING POINT 3A[a]

	Sampling Date
	Sept 1976
Parameter	
Flow (liter/min)	--
pH	7.95
Dissolved O_2 (mg/liter)	9.3
Acidity (mg/liter as $CaCO_3$)	--
Alkalinity (mg/liter as $CaCO_3$)	354
Conductivity (umhos/cm)	2,840
Pollutant (mg/liter)	
Aluminum	4.4
Cadmium	--
Chloride	377
Copper	--
Ferrous iron	1.9
Total iron	40
Lead	--
Magnesium	65
Manganese	5.2
Mercury	<0.0001
Nickel	--
Sulfate	1,600
Zinc	0.24

---

a. Combined slurry pond seepage and refuse pile drainage.

TABLE A-10. WATER QUALITY DATA: SITE B, SAMPLING POINT 4[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	1,140	50	800	190
pH	6.45	7.95	7.90	8.15
Dissolved O_2 (mg/liter)	--	9.3	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	158	354	226	230
Conductivity (umhos/cm)	2,000	2,840	1,300	2,300
Pollutant (mg/liter)				
Aluminum	0.94	4.4	1.8	0.32
Cadmium	<0.001	--	0.003	0.007
Chloride	--	377	75	110
Copper	0.003	--	0.008	0.009
Ferrous iron	0.1	1.9	0.04	0.08
Total iron	3.53	40	13	9.9
Lead	0.076	--	0.006	0.002
Magnesium	29	65	28	34
Manganese	1.58	5.2	2.3	1.5
Mercury	0.011	<0.0001	<0.0001	<0.0001
Nickel	0.0004	--	0.041	0.038
Sulfate	850	1,600	540	1,100
Zinc	0.03	0.24	0.04	0.03

---

a. Downstream from confluence of diversion ditch and Sampling Point 3 flow.

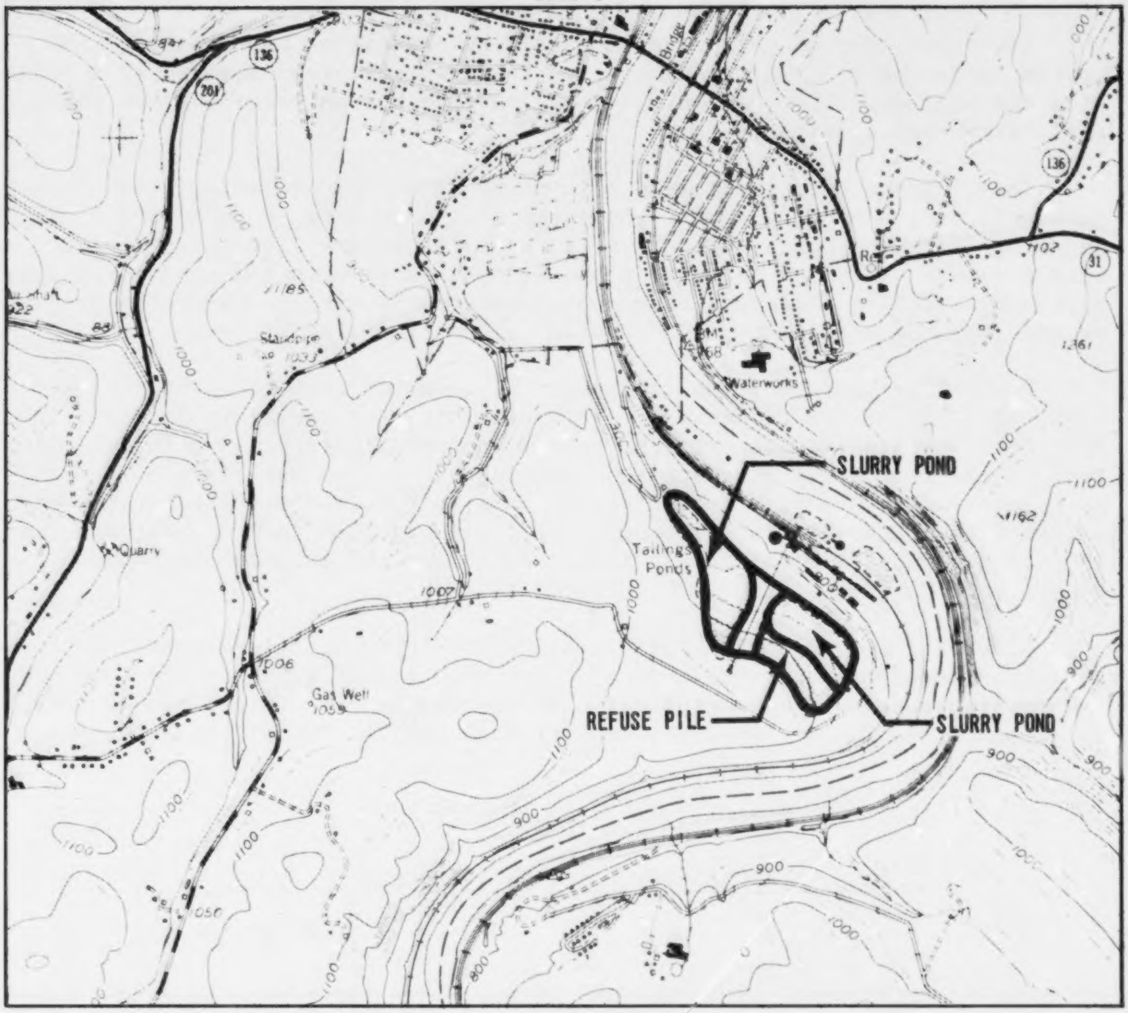
TABLE A-11. AIR QUALITY DATA: SITE B[a]

	Sampling Date				
	12/21/76	1/19/77	4/28/77	6/20/77	Average
Temperature (°C)	-5	-26	21 - 27	27 - 29	
Weather Conditions	Snow flurries, 3"-4" of snow	Ground frozen, snow-covered	Fair	Hazy, damp	
Wind Speed (mps)	3.7	2.2	0.3 - 0.5	4.0	
Wind Speed (mph)	8.5	5	0.5 - 1	8	
Wind Direction	NW	W	W	WSW	
Dust/Particulates (mg/liter)	0.017	0.010	0.030	0.004	0.02
Gases (mg/liter)					
Nitrogen dioxide	0.044	<0.01	0.040	0.027	0.03
Sulfur dioxide	<0.110	<0.01	0.010	0.003	0.03
Hydrogen sulfide	<0.09	<0.03	0.006	0.011	0.03
Carbon monoxide	1.7	1.3	2.5	1.9	1.8
Methane	3.0	3.3	3.0	3.4	3.2

---

[a] Sampling point 200 feet from dumping area, center of western edge of area.

SITE C


SLURRY POND
REFUSE PILE
SLURRY POND
Tailings Ponds
Waterworks
Quarry
Gas Well
Standpipe
136
201
31
1100
1000
900
800

HYDROLOGIC DATA

Drainage Area:	19 ha (47 acres). No tributary drainage to disposal site.
Precipitation (mean annual):	107 cm (42 in.)
Pond Evaporation (average annual):	76 cm (30 in.)
Temperature Extremes (Jan-July):	Mean max. 6°C (42°F) to 29°C (84°F) Mean min. -4°C (24°F) to 17°C (62°F)

Rainfall Design Frequencies: (24-hour storms)

	5-yr	10-yr	50-yr	100-yr
Depth, cm (in.)	8.4(3.3)	9.9(3.9)	12.2(4.8)	13.2(5.2)
Max. Storm Water Volume, $m^3 x 10^3$ (acre-ft)	5(4)	6(5)	7(6)	9(7)

SITE C: FEATURES AND OPERATIONS

The topography at this site is a sloping transition between flat river-bottom lands and rolling upland hills. The disposal area consists of a refuse pile and adjacent slurry ponds. The closed dike system retaining the ponds is built from coarse refuse.

The disposal area is divided into three basic compartments. The northwest area is an inactive slurry pond, the southeast area is an active slurry and mine drainage pond, and the central area is the dry disposal site for coarse refuse. Surface drainage from the uplands is diverted around the dike system by means of a ditch. Since water percolates through the permeable base of the impoundments, there are no outlet or spillway facilities.

Presently, coarse refuse is brought by conveyor from the preparation plant to a bin at the refuse area. From the bin, the refuse is loaded into a Model 631C Caterpillar scraper and spread in approximately 15 cm (6 in.) lifts. Compaction is achieved by systematic routing of the haulage equipment. Haul roads are maintained with two D-7 bulldozers. The dikes are continually being raised with coarse refuse. Approximately 774 Mt/d (850 tpd) of coarse refuse is placed in the disposal area. The gradation of the material is between the No. 28 and the 10 cm (4 in.) Tyler sieve sizes.

Slurry containing approximately 14% solids by weight is discharged from the wash plant to the active pond at a typical rate of 636 m^3/d (168,000 gpd). Mine drainage underflow is discharged at a variable rate into the same pond. The fine refuse in the slurry is smaller than the No. 28 Tyler sieve size.

DIMENSIONAL DATA

Slurry Pond Embankments	
Crest width	9-31 m (30-100 ft)
U/S slope	1.4:1
D/S slope	1.4:1[a]
Max. vert. distance to foundation	38 m (125 ft)

Slurry Ponds (Nos. 1, 2, 3)	
Total normal storage area	34 ha (84 acres)
Freeboard	2 - 5 m (7 - 15 ft)
Total existing storage volume	408,000 m^3 (533,000 yd^3)

Coarse Refuse Area	
Area	4.25 ha (10.5 acres)/yr
Surface slopes	±5%
Side slopes	1.4:1[a]
Max. depth (projected)	27 m (90 ft)
Storage volume	1,440,000 m^3 (1,880,000 yd^3)

---

[a] To be flattened to 2:1 in near future.

TYPE OF REFUSE AND PRIOR PROCESSING

The coal mined at this facility is from a seam approximately 2 m (7 ft) thick which is located at a depth of 76 m (250 ft) below the valley bottom. It is a low-sulfur metallurgical coal, mined using conventional room and pillar techniques. Whenever possible, the pillars are recovered when retreating. Coal brought to the preparation plant is processed using heavy media, froth flotation, and water table circuits. Approximately 3,640 Mt (4,000 tons) of raw coal are mined per day. Twenty-five percent or approximately 910 Mt (1,000 tons) per day of the total extraction is rejected. Coarse refuse accounts for 85% of the total reject, and fine refuse for 15%.

POLLUTION CONTROL CONSIDERATIONS

- The major part of the drainage from the refuse pile is directed into the slurry pond.
- The major portion of liquids entering the slurry ponds seeps out of the previous pond bottom. There is no water return from the ponds to the preparation plant.
- Sampling and testing of minor seepage through the coarse refuse dikes into drainage ditches provide the bases for evaluating pollution control.

AERIAL VIEW OF ACTIVE REFUSE PILE AND SLURRY POND. PREPARATION PLANT IS IN THE FOREGROUND WITH THE REFUSE CONVEYOR RUNNING FROM THE PLANT TO THE REFUSE PILE.

NORTHERN SLURRY PONDS. NOTE PERIMETER DITCH VISIBLE TO THE RIGHT OF THE ENCLOSING DIKE SYSTEM. PREPARATION PLANT THICKENER IS AT UPPER LEFT.

GENERAL VIEW OF SLURRY PONDS. THE POND TO THE RIGHT IS THE ACTIVE AREA, AND THE POND TO THE LEFT IS INACTIVE. SEPARATING THE TWO PONDS IS THE REFUSE CONVEYOR ALIGNMENT (RIGHT CENTER).

CREST OF THE COARSE REFUSE DIKE SYSTEM ENCLOSING THE SLURRY PONDS. THE CREST WIDTH IN THIS AREA IS APPROXIMATELY 50 FT. NOTE THAT THE CREST IS SLOPED TO DRAIN INTO THE SLURRY POND (RIGHT) AND NOT TOWARDS THE EMBANKMENT'S OUTSIDE SLOPE. TO THE LEFT OF THE EMBANKMENT, THE PREPARATION PLANT CAN BE SEEN.

TABLE A-12. SUMMARY OF WATER QUALITY DATA: SITE C
(Averages for four site visits)

	Sampling Point				Increase (+) or Decrease (-) between Inlet and Outlet Points
	1 (Inlet)[a]	2 (outlet)[b]	3[c]	4[d]	
Parameter					
Flow (liter/min)	17	96 - 380	30 - 88	20	+79 - +313
pH	8.0	7.4	8.0	7.3	-0.6
Dissolved O_2 (mg/liter)	8.8	9.9	11.4	--	+1.1
Acidity (mg/liter as $CaCO_3$)	--	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	287	146	205	202	-141
Conductivity (umhos/cm)	594	2,368	2,608	2,920	+1,774
Pollutant (mg/liter)					
Aluminum	0.48	1.41	2.38	1.70	+0.93
Cadmium	<0.001	0.005	0.004	0.001	+0.004
Chloride	13	28	61	--	+15
Copper	0.002	0.014	0.026	0.001	+0.012
Ferrous iron	0.07	1.00	0.11	0.10	+0.93
Total iron	0.47	5.57	8.63	4.90	+5.10
Lead	0.009	0.018	0.035	0.014	+0.009
Magnesium	16	79	86	118	+63
Manganese	0.08	5.52	8.40	4.8	+5.44
Mercury	<0.0001	<0.0001	<0.0001	0.0002	None
Nickel	0.017	0.028	0.075	0.037	+0.017
Sulfate	274	1,700	1,575	2,600	+1,426
Zinc	0.01	0.05	0.20	0.04	+0.04

---

a. Diversion ditch uphill from slurry pond area.
b. Downstream from confluence of diversion ditch and slurry pond seepage.
c. Diversion ditch parallel to and between the two slurry ponds.
d. Small seepage area at right side of impoundment.

TABLE A-13. WATER QUALITY DATA: SITE C, SAMPLING POINT 1[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	16	Standing	3	48
pH	8.10	7.90	8.00	7.90
Dissolved O_2 (mg/liter)	--	8.8	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	296	311	268	272
Conductivity (umhos/cm)	445	660	540	730
Pollutant (mg/liter)				
Aluminum	0.87	0.49	0.45	0.11
Cadmium	<0.001	--	<0.001	0.001
Chloride	--	15	12	12
Copper	0.003	--	0.002	<0.001
Ferrous iron	0.2	0.05	0.01	0.01
Total iron	1.07	0.10	0.41	0.31
Lead	0.017	--	0.003	0.006
Magnesium	13.1	12	17	20
Manganese	0.15	0.03	0.08	0.05
Mercury	0.0002	<0.0001	<0.0001	<0.0001
Nickel	<0.001	--	0.044	0.005
Sulfate	60	84	71	880
Zinc	0.01	0.01	0.01	0.02

---

a. Diversion ditch uphill from slurry pond area.

TABLE A-14. WATER QUALITY DATA: SITE C, SAMPLING POINT 2[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	280 - 380	90	13	1
pH	7.50	7.70	7.40	7.20
Dissolved O_2 (mg/liter)	--	9.9	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	129	149	152	153
Conductivity (umhos/cm)	1,750	2,420	1,900	3,400
Pollutant (mg/liter)				
Aluminum	4.6	0.20	0.38	0.45
Cadmium	<0.001	--	0.001	0.013
Chloride	--	26	31	28
Copper	0.012	--	0.007	0.023
Ferrous iron	0.1	0.16	3.6	0.15
Total iron	7.9	2.09	9.9	2.4
Lead	0.040	--	0.006	0.008
Magnesium	63	64	60	130
Manganese	2.9	2.8	4.4	12
Mercury	0.0005	<0.0001	<0.0001	<0.0001
Nickel	0.054	--	0.032	0.028
Sulfate	1,400	1,600	1,200	2,600
Zinc	0.07	0.03	0.07	0.017

---

a. Downstream from confluence of diversion ditch and slurry pond seepage.

TABLE A-15. WATER QUALITY DATA: SITE C, SAMPLING POINT 3[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	50 - 100	30	10	76
pH	7.85	7.85	8.20	8.25
Dissolved O_2 (mg/liter)	--	11.4	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	217	201	218	184
Conductivity (umhos/cm)	2,020	2,810	2,600	3,000
Pollutant (mg/liter)				
Aluminum	1.9	1.9	4.9	0.82
Cadmium	<0.001	--	0.001	0.011
Chloride	--	75	51	58
Copper	0.017	--	0.028	0.032
Ferrous iron	0.2	0.19	0.03	0.10
Total iron	5.7	2.93	22	3.9
Lead	0.012	--	0.032	0.06
Magnesium	79	88	85	93
Manganese	9.1	8.8	6.7	9.0
Mercury	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.082	--	0.059	0.085
Sulfate	1,500	1,900	1,100	1,800
Zinc	0.13	0.49	0.11	0.09

---

a. Diversion ditch parallel to and between the two slurry ponds.

TABLE A-16. WATER QUALITY DATA: SITE C, SAMPLING POINT 4[a]

	Sampling Date
	July 1976
Parameter	
Flow (liter/min)	20
pH	7.30
Dissolved O_2 (mg/liter)	--
Acidity (mg/liter as $CaCO_3$)	--
Alkalinity (mg/liter as $CaCO_3$)	202
Conductivity (umhos/cm)	2,920
Pollutant (mg/liter)	
Aluminum	1.7
Cadmium	0.001
Chloride	--
Copper	0.001
Ferrous iron	0.1
Total iron	4.9
Lead	0.014
Magnesium	118
Manganese	4.8
Mercury	0.0002
Nickel	0.037
Sulfate	2,600
Zinc	0.04

---

a. Small seepage area at right side of impoundment.

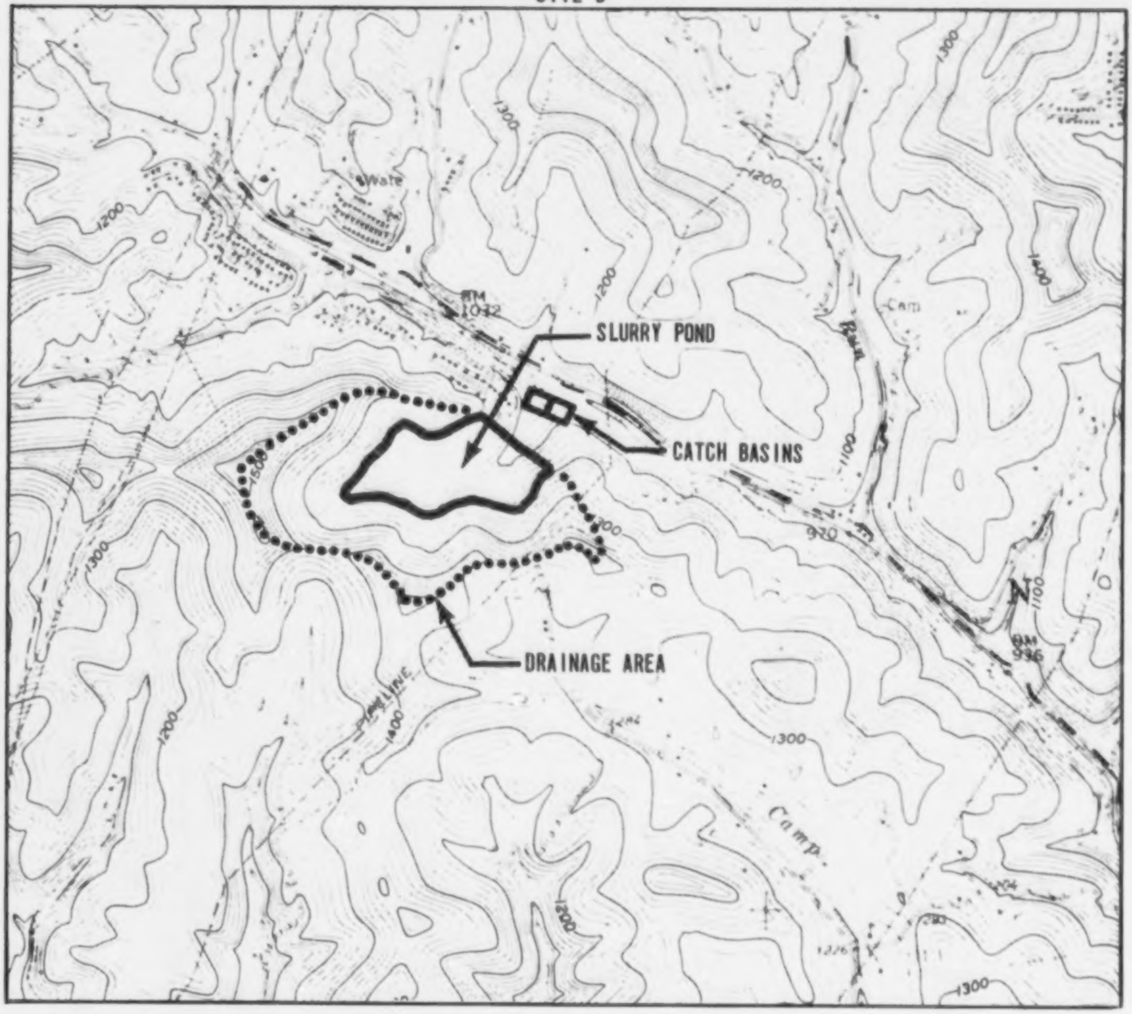
TABLE A-17. AIR QUALITY DATA: SITE C[a]

	Sampling Date				
	12/15/76	1/27/77	5/18/77	6/23/77	Average
Temperature (°C)	-1	-23 - -17	4 - 10	27 - 32	
Weather Conditions	Clear, 1/2" snow	Cold, ground frozen	Wet, rained last hour of test	Clear, dry	
Wind Speed (mps)	2.0	2.2	2.6	0.5 - 0.9	
Wind Speed (mph)	4.5	5	6	1 - 2	
Wind Direction	S	W	N	SW	
Dust/Particulates (mg/liter)	0.066	0.010	0.020	0.030	0.03
Gases (mg/liter)					
Nitrogen dioxide	0.067	<0.01	0.044	0.040	0.04
Sulfur dioxide	0.120	<0.01	0.082	0.078	0.07
Hydrogen sulfide	<0.07	<0.03	0.002	0.002	0.02
Carbon monoxide	1.5	1.1	1.5	1.5	1.4
Methane	3.4	3.0	3.8	3.7	3.5

---

a. Sampling point east and south of east pond.

SITE D


SLURRY POND
CATCH BASINS
DRAINAGE AREA
1300
1200
1400
BM 1032
970
N
BM 936
Camp
Run
PIPELINE
1500

HYDROLOGIC DATA

Drainage Area: 44 ha (109 acres)
Precipitation (mean annual): 114 cm (45 in.)
Pond Evaporation (average annual): 64 cm (25 in.)
Temperature Extremes (Jan-July): Mean max. 6.7°C (44°F) to 30°C (86°F)
Mean min. -4.4°C (24°F) to 15.6°C (60°F)
Rainfall Design Frequencies: (24-hour storms)

	5-yr	10-yr	50-yr	100-yr
Depth, cm (in.)	8.6(3.4)	9.9(3.9)	12.4(4.9)	13.5(5.3)
Est. Storm Water Volume, $m^3 x 10^3$ (acre-ft)	37(30)	43(35)	54(44)	59(48)

SITE D: FEATURES AND OPERATIONS

This coal waste disposal site is in mountainous terrain with a maximum relief of approximately 122 m (400 ft). Coarse refuse is used to construct a cross-valley dam which retains the slurry impoundment. Immediately downstream of the dam are two catch basins, each 3.05 m (10 ft) high, that extend over 0.4 ha (1 acre). These catch basins collect any seepage waters that exit at the downstream toe of the dam. From the catch basins the seepage water is pumped to a water treatment facility, treated, and then returned to the slurry impoundment.

The dam is constantly raised with coarse refuse brought in 18.2 Mt (20-ton) Euclid dump trucks to the top of the dam, where it is dumped into piles. A D-7 tractor then levels the piles into lifts approximately 30 to 46 cm (12 to 18 in.) thick. Compaction is achieved by routing of the equipment on each lift. The crest of the embankment is sloped toward the impoundment to prevent ponding and to minimize erosion of the downstream slope. An open-cut spillway, founded in rock, is located on the right abutment.

Additional refuse storage is located upstream of the impoundment. This supplementary area is a valley-fill type of refuse pile which was not in operation during our site visits.

The slurry pipe from the preparation plant discharges, at an average rate of 1,090 m^3pd (288,000 gpd) with 15% solids by weight, into the northern end of the impoundment near the dam. A diversion dike, built of refuse, has been constructed into the pond to direct the slurry toward the upstream portion of the retention area. The water level in the impoundment is controlled by a system of pumps, located near the spillway, which discharge excess water into a nearby creek. Very heavy storm waters would pass over the spillway.

DIMENSIONAL DATA

Retention Dam/Refuse Area	
Crest length	346 m (1,135 ft)
Crest width	128 m (420 ft)
D/S slope	2½:1
Max. vert. distance to foundation	43 m (140 ft)
Approximate volume	3.825(10^6) m^3 (5,000,000 yd^3)

Slurry Pond	
Maximum storage pond area	5.7 ha (14 acres)
Normal storage pond area	5.7 ha (14 acres)
Freeboard	3.05 m (10± ft)

TYPE OF REFUSE AND PRIOR PROCESSING

The coal mined at this site is from a seam which is 2.1 to 2.4 m (6.9 to 7.8 ft) thick, located at a depth of 91 to 244 m (300 to 800 ft) below the ground surface. It is a steam coal with approximately 3% sulfur. The preparation plant uses a Baum jig to clean the coal. Separation of the coarse refuse is at approximately the No. 10 Tyler sieve size. Mining is done using conventional room and pillar techniques with continuous miners. The raw coal production at the mine is approximately 4,550 Mt/d (5,000 tpd), with roughly 25% reject. Seventeen percent of the total production is coarse reject and 8 percent fine reject. Slurry disposal was started in 1951. It is not known when refuse disposal was first started.

POLLUTION CONTROL CONSIDERATIONS

- Significant volumes of polluted seepage water come out of the toe of the refuse dam that retains the slurry pond. These waters, collected in small, downstream catch basins, are chemically treated and returned to the pond.

- Drainage from the refuse areas is directed into the slurry pond. In accordance with regulatory requirements, excess pond waters are pumped over the dam into a nearby creek (open-water circuit).

- Water sampling and testing of a nearby creek upstream and downstream of the refuse area allow pollution control to be evaluated.

- The older surface of the embankment has been regraded and seeded to reduce erosion.

- The toe area of the embankment above the catch basin is being regraded to control all seepage into the basin. Seeding will be done upon completion of grading.

GENERAL VIEW OF SLURRY POND. THE REFUSE PILE EXTENDS OUT INTO THE POND TO DIVERT THE SLURRY TOWARDS THE UPPER PORTION OF THE POND AREA. THUS GRAVITY DRAINAGE INCREASES THE POND'S EFFICIENCY IN SETTLING SOLIDS.

TOE OF REFUSE DAM, WITH CATCH BASINS IN THE BACKGROUND. NOTE HEAVY SEEPAGE (APPROXIMATELY 125 GPM) FROM NEAR THE BASE OF THE DAM. MAIN STREAM CHANNEL IS IMMEDIATELY BEYOND CATCH BASINS.

TABLE A-18. SUMMARY OF WATER QUALITY DATA: SITE D
(Averages for four site visits)

	Sampling Point				Increase (+) or Decrease (-) between Inlet and Outlet Points
	1[a]	2 (Inlet)[b]	3 (Outlet)[c]	Seepage Point[d]	
Parameter					
Flow (liter/min)	265	1,700	1,552	Standing	-148
pH	5.9	7.4	6.6	5.3	-0.8
Dissolved O_2 (mg/liter)	--	10.8	11.0	--	+0.2
Acidity (mg/liter as $CaCO_3$)	--	--	24	--	+24
Alkalinity (mg/liter as $CaCO_3$)	50	75	35	5	-40
Conductivity (umhos/cm)	4,060	665	990	--	+325
Pollutant (mg/liter)					
Aluminum	4.8	1.0	4.1	42.0	+3.1
Cadmium	<0.001	0.002	0.002	0.001	None
Chloride	--	16	16	--	None
Copper	0.003	0.002	0.013	0.007	+0.011
Ferrous iron	600	0.12	6.95	430	+6.83
Total iron	175	2.67	11.80	236	+9.13
Lead	0.001	0.006	0.012	0.052	+0.006
Magnesium	105	15	24	125	+9
Manganese	10	0.74	2.70	15	+1.96
Mercury	<0.0001	<0.0001	<0.0001	<0.0001	None
Nickel	0.009	0.008	0.029	0.160	+0.021
Sulfate	2,700	262	565	2,900	+203
Zinc	0.12	0.04	0.10	0.35	+0.06

---

a. Embankment seepage entering catch basin.
b. Stream sample, upstream from site.
c. Stream sample, downstream from site.
d. Small seepage area on left abutment of embankment.

TABLE A-19. WATER QUALITY DATA: SITE D, SAMPLING POINT 1[a]

	Sampling Date July 1976
Parameter	
Flow (liter/min)	265
pH	5.90
Dissolved O_2 (mg/liter)	--
Acidity (mg/liter as $CaCO_3$)	--
Alkalinity (mg/liter as $CaCO_3$)	50
Conductivity (umhos/cm)	4,060
Pollutant (mg/liter)	
Aluminum	4.8
Cadmium	<0.001
Chloride	--
Copper	0.003
Ferrous iron	600
Total iron	175
Lead	0.001
Magnesium	105
Manganese	10
Mercury	<0.0001
Nickel	0.009
Sulfate	2,700
Zinc	0.12

---

a. Embankment seepage entering catch basin.

TABLE A-20. WATER QUALITY DATA: SITE D, SAMPLING POINT 2[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	--	2,200	1,700	1,200
pH	7.20	7.50	7.25	7.80
Dissolved O_2 (mg/liter)	--	10.8	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	67	88	58	86
Conductivity (umhos/cm)	700	750	460	750
Pollutant (mg/liter)				
Aluminum	0.58	2.2	0.91	0.29
Cadmium	<0.001	--	0.002	0.004
Chloride	--	14	15	19
Copper	0.002	--	0.003	0.001
Ferrous iron	0.1	0.26	0.20	0.01
Total iron	0.23	9.0	0.98	0.47
Lead	0.006	--	0.010	0.002
Magnesium	16.9	18	14	13
Manganese	0.66	0.99	0.76	0.55
Mercury	0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.011	--	0.007	0.006
Sulfate	280	370	190	210
Zinc	0.02	0.06	0.06	0.02

---

a. Upstream from site.

TABLE A-21. WATER QUALITY DATA: SITE D, SAMPLING POINT 3[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	610	2,700	1,700	1,200
pH	6.15	6.95	7.00	6.30
Dissolved O_2 (mg/liter)	--	11.0	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	24
Alkalinity (mg/liter as $CaCO_3$)	22	52	45	21
Conductivity (umhos/cm)	1,030	1,010	720	1,200
Pollutant (mg/liter)				
Aluminum	4.5	3.5	2.1	6.4
Cadmium	<0.001	--	0.003	0.002
Chloride	--	14	16	18
Copper	0.008	--	0.009	0.022
Ferrous iron	15	3.5	3.6	5.69
Total iron	14	6.9	7.3	19
Lead	0.008	--	0.009	0.020
Magnesium	25.3	26	21	24
Manganese	4	2.4	2.0	2.4
Mercury	0.0007	<0.0001	<0.0001	<0.0001
Nickel	0.038	--	0.012	0.038
Sulfate	490	590	420	760
Zinc	0.09	0.06	0.08	0.18

---

[a] Downstream from site.

TABLE A-22. WATER QUALITY DATA: SITE D, SAMPLING POINT[a]

	Sampling Date
	July 1976
Parameter	
Flow (liter/min)	Standing
pH	5.30
Dissolved O_2 (mg/liter)	--
Acidity (mg/liter as $CaCO_3$)	--
Alkalinity (mg/liter as $CaCO_3$)	5
Conductivity (umhos/cm)	--
Pollutant (mg/liter)	
Aluminum	42
Cadmium	0.001
Chloride	--
Copper	0.007
Ferrous iron	430
Total iron	236
Lead	0.052
Magnesium	125
Manganese	15
Mercury	<0.0001
Nickel	0.16
Sulfate	2,900
Zinc	0.35

---

a. Left abutment of embankment.

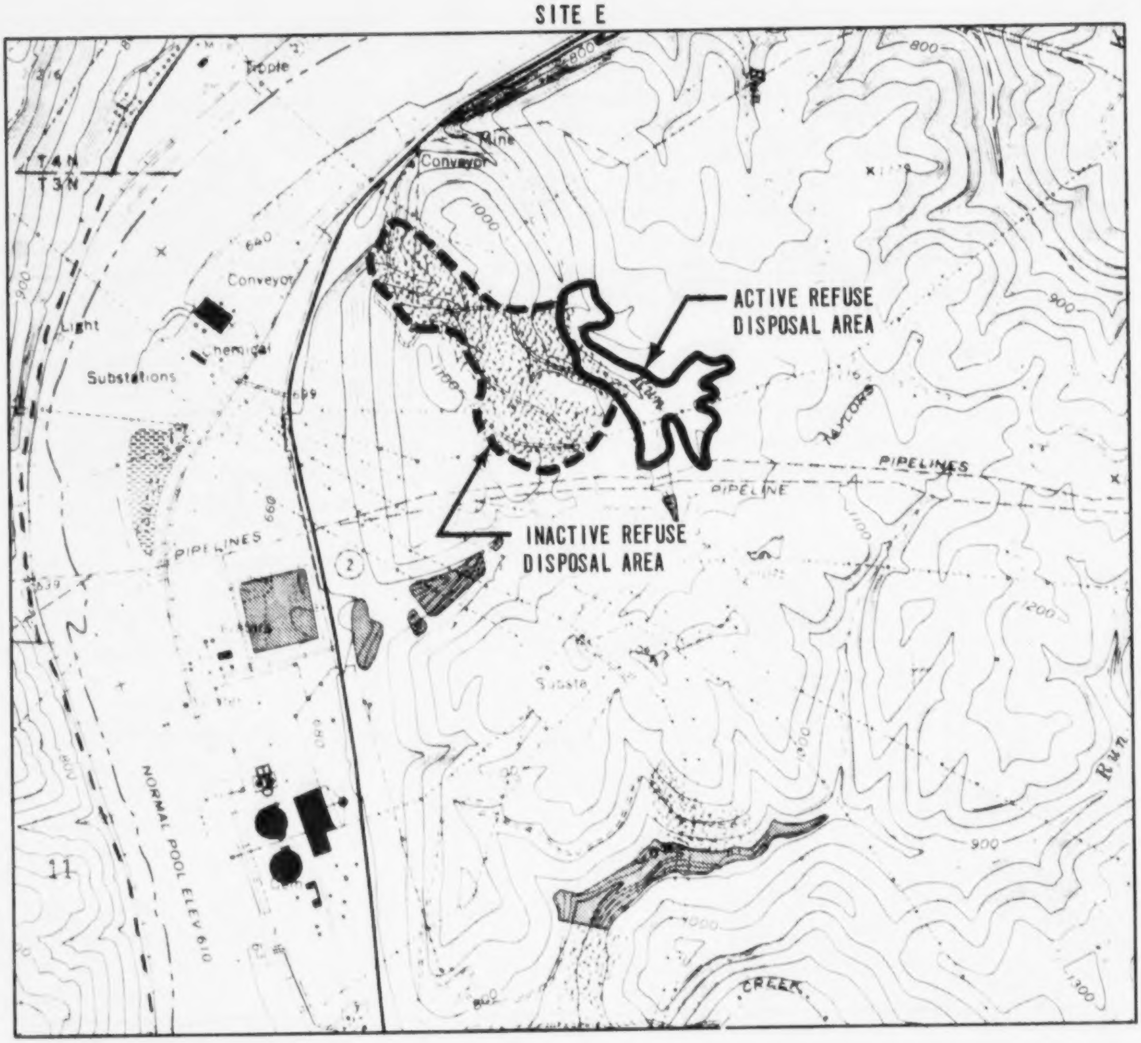
TABLE A-23. AIR QUALITY DATA: SITE D[a]

	Sampling Date				
	12/20/76	1/20/77	5/17/77	6/23/77	Average
Temperature (°C)	-1 - 0.5	-26	27	27	
Weather Conditions	Rain, sleet, water in ruts	Ground frozen, 18" snow	Hot, hazy	Clean, dry	
Wind Speed (mps)	1.5 - 2.0	2.2	1.4	0.5 - 0.9	
Wind Speed (mph)	4 - 5	5	3	1 - 2	
Wind Direction	SSW-SW	WNW	SW	S	
Dust/Particulates (mg/liter)	0.033	0.010	0.033	0.04	0.03
Gases (mg/liter)					
Nitrogen dioxide	0.077	<0.01	0.077	0.040	0.05
Sulfur dioxide	0.07	<0.01	0.07	0.074	0.05
Hydrogen sulfide	<0.07	<0.03	<0.07	0.004	0.03
Carbon monoxide	1.2	1.2	1.2	1.6	1.3
Methane	3.0	3.0	3.0	3.3	3.1

---

a. Sampling point 100 yards south of pond.

SITE E


ACTIVE REFUSE DISPOSAL AREA
INACTIVE REFUSE DISPOSAL AREA
Tipple
T4N
T3N
Mine
Conveyor
Conveyor
Light
Chemical
Substations
Substa
PIPELINES
PIPELINE
PIPELINES
NORMAL POOL ELEV 610
Run
Run
CREEK
2
11
640
660
680
800
900
1000
1100
1200
1300

HYDROLOGIC DATA

Drainage Area: 81 ha (200 acres)
Precipitation (mean annual): 102 cm (40 in.)
Pond Evaporation (average annual): 76 cm (30 in.)
Temperature Extremes (Jan-July): Mean max. 6°C (42°F) to 31°C (88°F)
Mean min. -4°C (24°F) to 17°C (62°F)

Rainfall Design Frequencies: (24-hour storms)

	5-yr	10-yr	50-yr	100-yr
Depth, cm (in.)	8.4(3.3)	9.9(3.9)	12.2(4.8)	13.2(5.2)
Est. Storm Water Volume m^3x10^3 (acre-ft)	40(32)	46(37)	57(46)	62(50)

SITE E: FEATURES AND OPERATIONS

Site E is in mountainous terrain typical of Appalachia and has a maximum relief of 122 m (400 ft). Disposal was started at this site in 1958 and displays a combination of valley-fill, sidehill, ridgetop, and heaped-pile disposal practices. In 1974, the mine operator concentrated disposal operations in an area where valley-fill practices are used exclusively. Site visits were restricted to this area, because it is the active sector of the larger disposal area. There is an emergency disposal area at the top western portion of the refuse pile adjacent to the storage bin.

The selected disposal area is a steep, narrow hollow which has numerous springs along the valley slopes. These springs, and accompanying landslide problems, are quite common to the area. Prior to placing refuse in this location, the area was cleared and grubbed. Most of the trees and heavy brush were put through a wood chipper and the chips were marketed by a forestry group assigned to the improvement of woodlands owned by the coal company.

After clearing and grubbing, a trial underdrain system was installed in one area to intercept spring water and carry it under the refuse. The underdrain system is composed of perforated pipes and a permeable blanket of boiler slag. The boiler slag is a waste product from one of the nearby steam-electric generating stations.

To intercept surface drainage, a perimeter ditch has been excavated into the hillside above the refuse. This ditch generally surrounds the refuse area and discharges the collected water downstream of the disposal area. The perimeter ditch is continually maintained to keep it clear of debris and to repair any local landslide conditions.

Refuse is taken by conveyor from the preparation plant to a storage bin adjacent to the disposal area. From the bin, the refuse is loaded into a Terex Model TS24 scraper with a capacity of 18 m^3 (24 yd^3), and is hauled to the head of the hollow, where it is placed in the downstream direction. The specified maximum lift thickness is 31 cm (12 in.); however, the scraper operators prefer to lay the refuse in lifts 15 to 20 cm (6 to 8 in.) thick. The surface of the active refuse area is projected to be crowned with a minimum slope of 1½%. Side slopes are a maximum of 2 (horizontal) to 1 (vertical). A water truck and D-7 bulldozer are used to maintain the haul roads. The bulldozer is also used in dressing the refuse area. An emergency refuse storage area at the downstream portion of the disposal area is used when the conveyor from the preparation plant is down. A 46 Mt (50-ton) dump truck hauls refuse directly from the preparation plant during conveyor shutdown periods. Restoration of the refuse is primarily accomplished during downtime periods, such as when the mine or preparation plant is temporarily out of production; however, it is an ongoing activity and is not totally limited to downtime periods. Restoration includes covering all finished refuse surfaces with 30 to 60 cm (1 to 2 ft) of clay soils, and seeding.

DIMENSIONAL DATA

Refuse Area	
Surface area	24.3 ha (60 acres)
Drainage area	81 ha approx. (200 acres)
Maximum height of refuse	76 m (250 ft)
Finished surface slope	1 to 1½%
Finished side slopes	Maximum 2:1

TYPE OF REFUSE AND PRIOR PROCESSING

Coal is mined at Site E from a seam located at an average depth of 120 to 180 m (400 to 600 ft) below ground surface. The coal is a high-sulfur steam coal approximately 1.5 m (5 ft) thick. In this area, the coal seam has a shale parting up to 46 cm (18 in.) thick. Mining operations remove both the coal and shale parting along with the materials later separated in the preparation plant. Continuous miners are presently used to extract the coal, but it is planned to use longwall operations in the near future.

The preparation plant uses a combination of froth flotation and heavy media circuits to clean the coal. In the heavy media circuit, the Chance cones use sand as their media. The coarse refuse is separated with screens at 1.1 cm (0.4 in.). Minus 1.1 cm (0.4 in.) material is mixed with the wash coarse size to obtain plant product.

Fine refuse (smaller than the No. 100 sieve) is pumped in slurry form behind a dam located on a nearby drainage channel. The dam is operated by a large utility company primarily as a retention basin for flyash. The run-of-the-mine coal production is approximately 9,100 Mt/d (10,000 tpd). Of this, approximately 17% is coarse reject. The reported coal chemistry is as follows:

Moisture	5.34%
Ash	14.63%
Sulfur	4.30%
Heat content	11,834 Btu

POLLUTION CONTROL CONSIDERATIONS

- There is no slurry pond associated with the refuse pile at this site.
- Some acid drainage enters the basin above the disposal area from inactive or abandoned refuse areas to the east of the active disposal area. As the active refuse area expands, much of the acid drainage from the inactive area should be blocked off to reduce the pollution potential.
- An interceptor ditch has been cut into the sides of the valley to divert a major part of incoming water around the refuse pile.

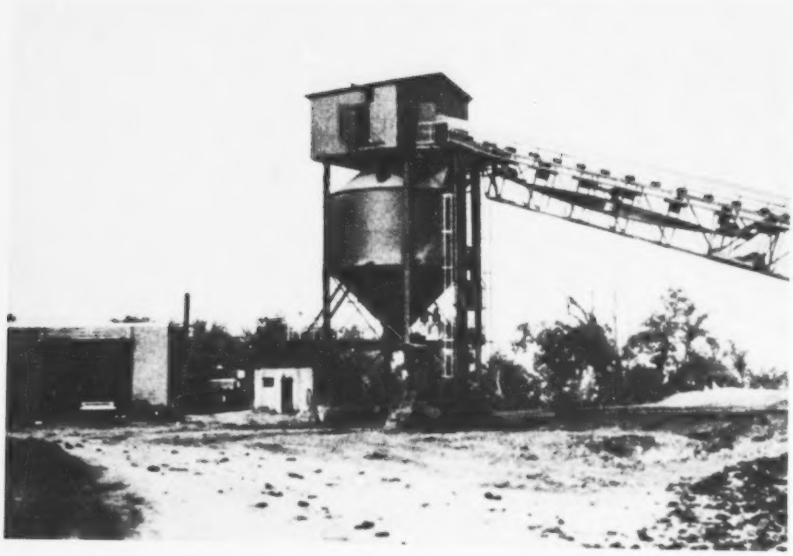
- The site is in difficult mountainous terrain with numerous springs; landsliding problems occur along the steep, heavily-wooded valley slopes.
- Stream flows above and below the refuse disposal area allow for water sampling and testing to evaluate pollution control at the refuse area.
- Any erosion of the refuse is contained on site.

Refuse disposal area viewed from near midpoint. Dark materials in foreground comprise active disposal area. Light colored materials in background are an older, inactive section. Drainage is maintained by the channel along the right side of the valley.

Surface of active refuse area. Heavy scrapers are able to pass over the refuse with a minimum of surface yielding. Relative firmness of surface is due to placement of fill in thin lifts.

DIVERSION DIH AROUND ONE OF THE VALLEY'S ABUTMENTS.
VALLEY SLOS AT THIS SITE ARE LANDSLIDE PRONE. NOTE
THAT THE CARING OF VEGETATION IS LIMITED TO MINIMUM.

DIVERSION DIT DIRECTING DRAINAGE WATER ALONG THE RIGHT
SIDE OF THEALLEY ABOVE THE REFUSE.



LOAD-OUT REFUSE BIN. THE CONVEYOR BELT HAS A TURN-OVER FEATURE ON THE RETURN LINE. THE TURN CLEANS THE BELT OF STICKING REFUSE PARTICLES AND THUS PREVENTS RANDOM DROPPING OF REFUSE MATERIAL ALONG THE CONVEYOR ALIGNMENT.

TABLE A-24. SUMMARY OF WATER QUALITY DATA: SITE E
(Averages for four site visits)

	Sampling Point				Increase (+) or Decrease (-) between Inlet and Outlet Points
	1 (Inlet)[a]	2[b]	3[c]	4 (Outlet)[d]	
Parameter					
Flow (liter/min)	38 - 75	139 - 280	19	347 - 950	309 - 875
pH	7.6	7.3	3.5	4.7	-2.9
Dissolved O_2 (mg/liter)	10.2	5.4	--	10.8	+0.6
Acidity (mg/liter as $CaCO_3$)	--	--	4,020	822	+822
Alkalinity (mg/liter as $CaCO_3$)	59	528	--	18	-41
Conductivity (umhos/cm)	623	3,460	8,900	4,493	+3,870
Pollutant (mg/liter)					
Aluminum	0.24	0.35	380	42.75	+42.51
Cadmium	0.001	0.003	0.027	0.007	+0.006
Chloride	4.3	311	--	209	+204.7
Copper	0.002	0.002	0.230	0.033	+0.031
Ferrous iron	0.10	3.04	510	300	+299.9
Total iron	0.24	6.88	1,210	351.75	+351.54
Lead	0.004	0.006	0.003	0.003	-0.001
Magnesium	7.4	22	350	111.8	+104.4
Manganese	0.19	6.3	36	29.5	+29.31
Mercury	<0.0001	<0.0001	0.0008	<0.0001	None
Nickel	0.002	0.004	0.320	0.410	+0.408
Sulfate	63	1,233	6,400	3,100	+3,037
Zinc	0.01	0.03	8	2.70	+2.69

---

a. Control sample from drainage above site.
b. Drainage from new fill area.
c. Drainage from new and old fill areas.
d. Composite of old and new fill areas, surface runoff, and adjacent spring water. Point is confluence of all water leaving site before going to treatment plant.

TABLE A-25. WATER QUALITY DATA: SITE E, SAMPLING POINT 1[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	75 - 150	Standing	Standing	Standing
pH	7.60	7.95	7.30	7.60
Dissolved O_2 (mg/liter)	--	10.2	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	45	70	65	56
Conductivity (umhos/cm)	1,800	202	250	240
Pollutant (mg/liter)				
Aluminum	0.28	0.33	0.27	0.09
Cadmium	<0.001	--	0.002	0.001
Chloride	--	1	8	4
Copper	0.001	--	0.003	<0.001
Ferrous iron	0.3	0.04	0.01	0.04
Total iron	0.3	0.23	0.35	0.08
Lead	<0.001	--	0.002	0.008
Magnesium	6.1	7	9.8	6.8
Manganese	0.12	0.31	0.18	0.13
Mercury	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	<0.001	--	0.004	0.001
Sulfate	38	42	110	61
Zinc	0.01	0.01	0.03	<0.001

---

a. Drainage point above site.

TABLE A-26. WATER QUALITY DATA: SITE E, SAMPLING POINT 2[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	190 - 280	170	280	57
pH	7.20	7.50	7.40	7.00
Dissolved O_2 (mg/liter)	--	5.4	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	543	567	531	472
Conductivity (umhos/cm)	5,100	4,740	1,500	2,500
Pollutant (mg/liter)				
Aluminum	0.39	0.60	0.22	0.17
Cadmium	0.002	--	0.002	0.006
Chloride	--	694	58	180
Copper	0.005	--	<0.001	<0.001
Ferrous iron	0.1	11	0.03	1.01
Total iron	2.13	15.2	3.0	7.2
Lead	<0.001	--	0.002	0.014
Magnesium	23.3	39	7.8	18
Manganese	0.76	2.3	0.52	1.8
Mercury	<0.0001	<0.0001	0.0005	<0.0001
Nickel	0.004	--	0.008	0.002
Sulfate	1,700	2,100	390	740
Zinc	0.02	0.07	0.03	0.01

---

a. New fill area.

TABLE A-27. WATER QUALITY DATA: SITE E, SAMPLING POINT 3[a]

	Sampling Date
Parameter	July 1976
Flow (liter/min)	19
pH	3.50
Dissolved O_2 (mg/liter)	--
Acidity (mg/liter as $CaCO_3$)	4,020
Alkalinity (mg/liter as $CaCO_3$)	--
Conductivity (umhos/cm)	8,900
Pollutant (mg/liter)	
Aluminum	380
Cadmium	0.027
Chloride	--
Copper	0.23
Ferrous iron	510
Total iron	1,210
Lead	0.003
Magnesium	305
Manganese	36
Mercury	0.0008
Nickel	0.32
Sulfate	6,400
Zinc	8.0

---

[a] Confluence of drainage from new and old fill areas.

TABLE A-28. WATER QUALITY DATA: SITE E, SAMPLING POINT 4[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	750 - 950	150	Frozen	140
pH	3.80	5.00	6.15	3.80
Dissolved O_2 (mg/liter)	--	10.8	--	--
Acidity (mg/liter as $CaCO_3$)	1,570	522	436	760
Alkalinity (mg/liter as $CaCO_3$)	--	--	18	--
Conductivity (umhos/cm)	6,300	4,670	2,800	4,200
Pollutant (mg/liter)				
Aluminum	85	29	29	28
Cadmium	0.007	--	0.001	0.014
Chloride	--	422	86	120
Copper	0.058	--	0.015	0.025
Ferrous iron	440	220	220	318
Total iron	560	267	260	320
Lead	0.001	--	0.008	0.001
Magnesium	166	113	75	93
Manganese	43	32	21	22
Mercury	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.31	--	0.69	0.23
Sulfate	4,200	3,400	2,100	2,700
Zinc	5.2	2.1	1.7	1.8

---

a. Confluence of waters leaving site.

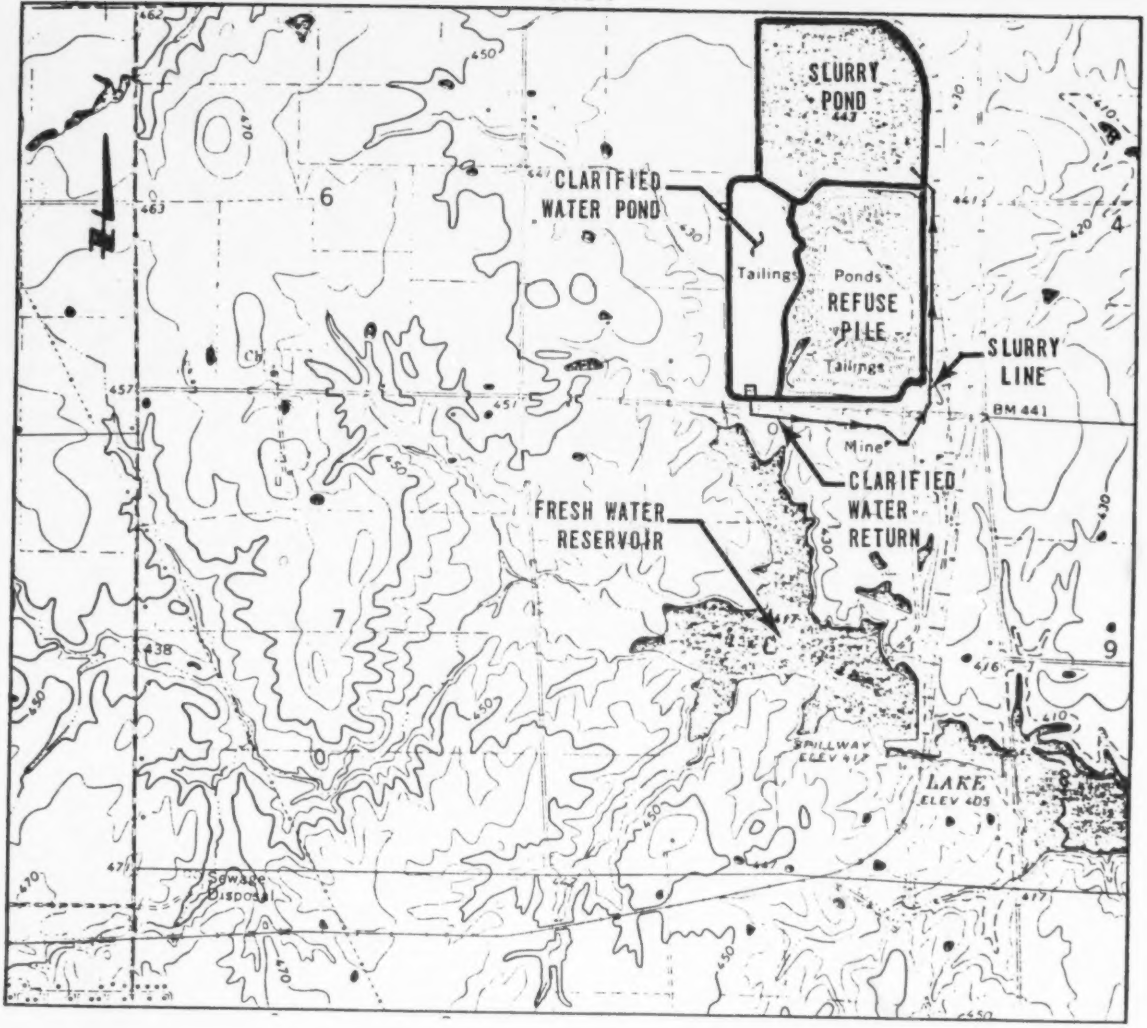
TABLE A-29. AIR QUALITY DATA: SITE E[a]

	Sampling Date				
	12/21/76	1/19/77	4/28/77	6/20/77	Average
Temperature (°C)	-12 - -10	-26	27 - 28	15 - 27	
Weather Conditions	Snow flurries, 3"-4" of snow	Ground frozen, 12"-18" snow	Fair	Hazy, ground damp	
Wind Speed (mps)	3.7 - 8.9	2.2	0 - 0.2	0 - 0.9	
Wind Speed (mph)	8 - 20	5	0 - 0.5	0 - 2	
Wind Direction	NW-NNW	W	W	W+E	
Dust/Particulates (mg/liter)	0.015	0.020	0.040	0.004	0.02
Gases (mg/liter)					
Nitrogen dioxide	0.048	<0.01	0.025	0.023	0.02
Sulfur dioxide	0.22	<0.01	0.010	0.002	0.06
Hydrogen sulfide	<0.09	<0.03	0.002	0.006	0.02
Carbon monoxide	1.7	1.2	2.3	1.8	1.8
Methane	3.1	3.3	2.8	3.7	3.2

---

a. Sampling point far eastern corner of area.

SITE F


SLURRY POND
443
CLARIFIED WATER POND
Tailings
Ponds
REFUSE PILE
Tailings
SLURRY LINE
BM 441
Mine
CLARIFIED WATER RETURN
FRESH WATER RESERVOIR
SPILLWAY ELEV 417
LAKE ELEV 405
Sewage Disposal
6
7
4
9
450
470
457
463
462
438
430
420
410

HYDROLOGIC DATA

Drainage Area: 81 ha (200 acres)
Precipitation (mean annual): 107 cm (42 in.)
Pond Evaporation (average annual): 89 cm (35 in.)
Temperature Extremes (Jan-July): Mean max. 7°C (44°F) to 26°C (90°F)
Mean min. -3°C (26°F) to 19°C (67°F)
Rainfall Design Frequencies: (24-hour storms)

	5-yr	10-yr	50-yr	100-yr
Depth, cm (in.)	10.7(4.2)	12.2(4.8)	15.7(6.2)	20-23(8-9)
Est. Storm Water Volume, m^3x10^3 (acre-ft)	49(40)	62(50)	74(60)	82(65)

SITE F: FEATURES AND OPERATIONS

Site F, a combined slurry impoundment and refuse disposal area, is located in typical Midwestern flatlands. The impoundment and disposal areas are totally retained by a perimeter dike system constructed of native clay soils.

The original slurry impoundment area is now used to dispose of the coarse refuse. There is a 24.4 m (80 ft) high mound of refuse in this area which was placed many years ago, before present-day disposal practices and regulations were put into effect. It is understood that this mound is to be graded to acceptable slopes in the future. Presently, coarse refuse from the preparation plant is being hauled to the disposal area in 20 Mt (22 ton) dump trucks and deposited in piles. A bulldozer periodically levels the piles in lifts 46 cm to 61 cm (18 in. to 24 in.) thick, and the equipment is routed over each lift to facilitate limited compaction. The surface of the refuse is sloped toward the clear-water pond to minimize drainage out of the dike system and to prevent ponding of water. There is no history of fires with this refuse pile.

The diked area north of the refuse area is used as the slurry impoundment. The slurry is pumped at approximately 2.27 m^3pm (600 gpm) into the southeast corner of this area and the solids allowed to settle. Clear water is then decanted into the clarified water pond through a divider dike constructed across the southwestern end of the impoundment. Water from the clarified water pond is returned to the coal preparation plant for reuse. There is no point source discharge into the natural streams. Makeup water is obtained at approximately 2.27 m^3pm (600 gpm) from a freshwater reservoir west and south of the preparation plant.

The perimeter dike has a heavy, volunteer growth of grasses and bushes on the downstream slope. The upstream slope is also protected with grasses, except where wave action has caused erosion problems. Plans are being developed by the mine owner to rehabilitate the portions of the dike system which have been damaged by wave action.

The slurry retention dikes were constructed in a sequential pattern, starting in 1959, near the southeast corner of the present site. As the storage area filled, new dikes were constructed until the entire system reached its present configuration.

DIMENSIONAL DATA

Refuse Area	
Surface Area	28.3 ha (70 acres)
Average depth	8.84 m (29± ft)
Storage volume	140,000 Mt (154,000 tons)
Average surface slope	(2%±)
Average side slopes	(2:1)

Slurry Impoundment	
Crest length	2,134 m (7,000 ft)
Crest width	0.91-3.05 m (3-10 ft)
U/S slope	(2:1)
D/S slope	(1.5:1)
Max. vert. distance to foundation	10.7 m (35 ft)
Surface area	32 ha (79 acres)
Storage volume	$1.224(10^6)$ Mt (1,345,000 tons)

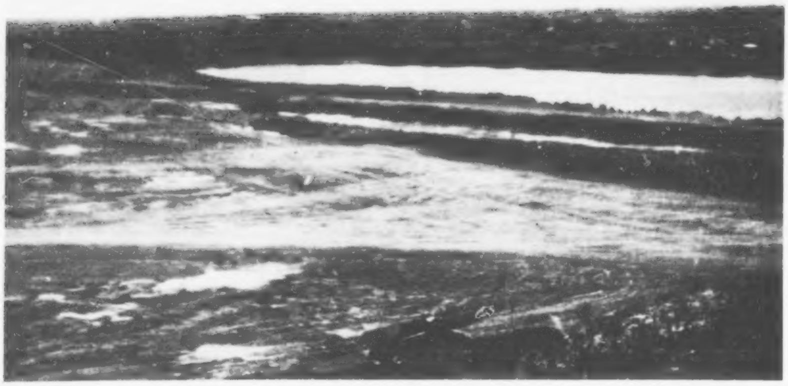
Clear Water Impoundment	
Maximum storage pond area	15.4 ha (38 acres)
Normal storage pond area	15.4 ha (38 acres)
Max. vert. distance to found.	(6.10 m (20 ft)
Freeboard	3.05 m (10± ft)
Spillway	None

TYPE OF REFUSE AND PRIOR PROCESSING

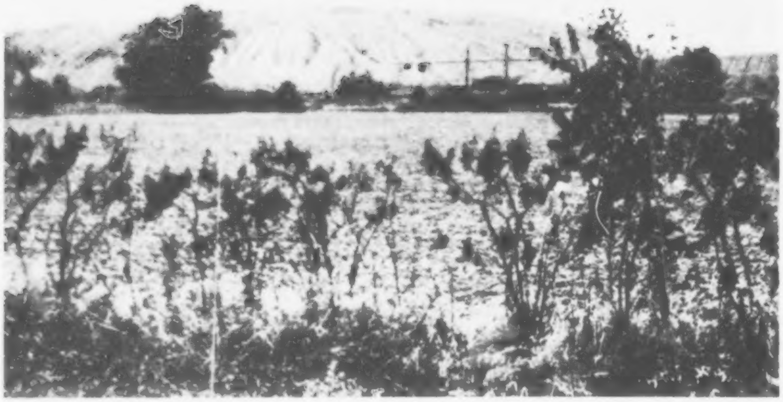
A low-sulfur metallurgical coal is mined at this facility. The seam averages 2.3 m (7.5 ft) thick and is located at an approximate depth of 200 m (660 ft). The coal is mined using continuous miners and room and pillar techniques developed by the mine operators. Coal brought to the preparation plant is processed using Baum jigs and a heavy media circuit. Approximately 8,190 Mt (9,000 tons) of raw coal are mined per day. Of this total, between 18% and 25% is rejected. The raw coal, as mined, has a reported typical analysis (dry basis) of approximately 1.5% sulfur and 15% to 20% ash.

POLLUTION CONTROL CONSIDERATIONS

- The preparation plant recirculates slurry pond waters; makeup water comes from a lake with a high domestic detergent load.
- The coarse refuse pile is located within the retention dike system.
- Drainage from the refuse pile is retained within the slurry pond and used in the plant water circuit.
- Any seepage from the clarified water pond is routed into the makeup water reservoir.



Partial view of the active coarse refuse area. Note that the refuse area is sloped into the clarified water pond. Refuse piles (left center and bottom center) have been recently dumped by trucks. A bulldozer from the preparation plant periodically levels and compacts the piles.



Inactive refuse pile placed in past years. This pile is completely contained by earth dikes. The structure will be regraded and reclaimed to conform to regulatory requirements.

SLURRY LINE DECANTING INTO THE SOUTHEAST CORNER OF THE SLURRY POND. THE VERY GENTLE TERRAIN SURROUNDING THE REFUSE AREA IS CHARACTERISTIC OF THIS REGION.

WATER QUALITY SAMPLING POINT, LOCATED IMMEDIATELY OUTSIDE THE SOUTHWEST CORNER OF THE CLARIFIED WATER POND. DURING RUNOFF EVENTS THIS CHANNEL IS OCCUPIED BY A MOVING STREAM. AT OTHER TIMES ANY WATER IN THIS PORTION OF THE CHANNEL REMAINS STAGNANT (AS SHOWN HERE).

TABLE A-30. SUMMARY OF WATER QUALITY DATA: SITE F, SAMPLING POINT 2[a]
(Averages for two site visits)

	Sampling Point 2[b]
Parameter	
Flow (liter/min)	Standing
pH	7.8
Dissolved O_2 (mg/liter)	9.0
Acidity (mg/liter as $CaCO_3$)	--
Alkalinity (mg/liter as $CaCO_3$)	96
Conductivity (umhos/cm)	2,315
Pollutant (mg/liter)	
Aluminum	3.2
Cadmium	0.002
Chloride	548
Copper	0.009
Ferrous iron	0.30
Total iron	5.18
Lead	0.019
Magnesium	36
Manganese	10.3
Mercury	<0.0001
Nickel	0.015
Sulfate	625
Zinc	0.04

---

a. At sampling point 1, the upstream control point, no water was found during either of the site visits.

b. Downstream from lower right abutment of dike.

TABLE A-31. WATER QUALITY DATA: SITE F, SAMPLING POINT 2[a]

	Sampling Date	
	July 1976	Sept 1976
Parameter		
Flow (liter/min)	Standing	Standing
pH	8.85	6.8
Dissolved O_2 (mg/liter)	--	9.0
Acidity (mg/liter as $CaCO_3$)	--	--
Alkalinity (mg/liter as $CaCO_3$)	167	24
Conductivity (umhos/cm)	3,050	1,580
Pollutant (mg/liter)		
Aluminum	4.0	2.3
Cadmium	0.002	--
Chloride	630	465
Copper	0.009	--
Ferrous iron	--	0.30
Total iron	6.7	3.65
Lead	0.019	--
Magnesium	46	27
Manganese	5.6	15
Mercury	<0.0001	<0.0001
Nickel	0.015	--
Sulfate	630	620
Zinc	0.04	0.05

---

a. Downstream from lower right abutment of dike.

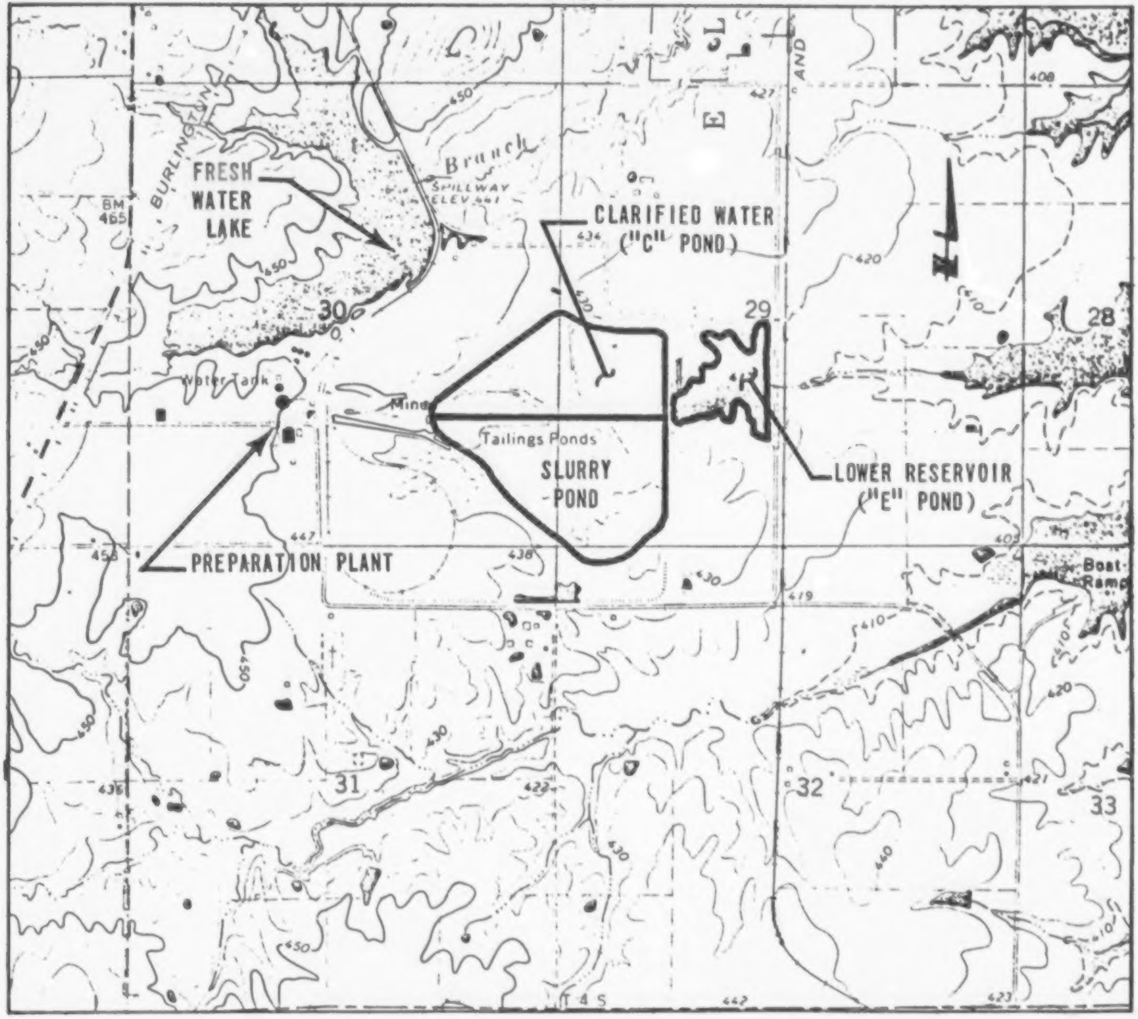
TABLE A-32. AIR QUALITY DATA: SITE F[a]

	Sampling Date				
	1/6/77	1/17/77	3/23/77	6/16/77	Average
Temperature (°C)	-2	-27	-1 - 4	18 - 24	
Weather Conditions	Light snow on ground, 2"-3"	Ground frozen, snow-covered	Wet	Fair, ground damp	
Wind Speed (mps)	1.6	4.5	3.2	1.1	
Wind Speed (mph)	4	10	7	2.5	
Wind Direction	SSW	NW	W+NW	SW	
Dust/Particulates (mg/liter)	0.022	0.010	0.020	0.020	0.018
Gases (mg/liter)					
Nitrogen dioxide	<0.01	<0.01	0.02	0.02	0.01
Sulfur dioxide	<0.01	<0.01	0.04	0.02	0.01
Hydrogen sulfide	<0.03	<0.03	0.01	0.03	0.01
Carbon monoxide	1.2	1.3	1.5	1.2	1.3
Methane	3.3	2.7	3.5	2.8	3.1

---

a. Sampling point off haulage road, 100 feet downwind of dumping area.

SITE G


FRESH
WATER
LAKE
CLARIFIED WATER
("C" POND)
SLURRY
POND
LOWER RESERVOIR
("E" POND)
PREPARATION PLANT
Tailings Ponds
Mine
Water Tank
Branch
SPILLWAY
BURLINGTON
BM
465
30
29
28
31
32
33
Boat
Ramp
T 4 S

HYDROLOGIC DATA

Drainage Area: 53 ha (130 acres)
Precipitation (mean annual): 107 cm (42 in.)
Pond Evaporation (average annual): 89 cm (35 in.)
Temperature Extremes (Jan-July): Mean max. 7°C (44°F) to 32°C (90°F)
Mean min. -3°C (26°F) to 19°C (67°F)
Rainfall Design Frequencies: (24-hour storms)

	5-yr	10-yr	50-yr	100-yr
Depth, cm (in.)	10.7(4.2)	12.2(4.8)	15.7(6.2)	17.0(6.7)
Est. Storm Water Volume, m^3x10^3 (acre-ft)	57(46)	62(50)	80(65)	86(70)

SITE G: FEATURES AND OPERATIONS

Site G is in typical Midwestern flatlands. The disposal area is a combined slurry impoundment and refuse dump; coarse refuse is used to build the dikes that retain the slurry pond. Surface drainage is directed around the outside perimeter of the dike system and collected in a small reservoir immediately downstream of the impoundment. Water collected in this reservoir is pumped back into the clarified water pond. Below this collection reservoir is a large, multipurpose reservoir constructed by the Corps of Engineers. North of the site is a fresh-water reservoir which was constructed and is being operated by the company as a source of makeup water for the preparation plant.

The pond area is divided into two compartments by a center divider dike. The southern compartment contains the slurry settling basin, and the northern compartment is used as a clarified water pond. The differential water head across the compartments is 3.05 m (10 ft) and is maintained by a decant pipe through the divider dike. Water in the clarified water pond is recycled back to the preparation plant. Makeup water is obtained from the clarified water pond and from the fresh-water reservoir. There is no point source discharge out of the ponds.

When the dike system was begun in 1967, native clay soils were used to construct a low starter embankment. Since then, coarse refuse has been used to raise the dikes. The refuse is hauled to the dikes with a 46 Mt (50 ton) dump truck and spread into 46 cm (18 in.) thick lifts with a D-8 Caterpillar. As a part of the truck hauling operations, the drivers are instructed to change the paths of their trucks so that each refuse layer is compacted with at least four to six coverages of the truck wheels. Additional compaction is achieved through the operation of the bulldozer in leveling the dumped refuse piles. During the site survey, safety berms were being constructed on the top inside and outside edges of the embankments to prevent vehicles from accidentally slipping off the dike crest.

DIMENSIONAL DATA

Embankment	
Crest length	3,048 m (10,000 ft)
Crest width	12-30 m (40-100 ft)
U.S slope	1.25:1
D/S slope	1.25:1
Max. vert. distance to foundation	10.7 m (35 ft)

Slurry Pond	
Maximum storage pond area	30.8 ha (76 acres)
Normal storage pond area	30.8 ha (76 acres)
Existing storage volume	$1.13(10^6)$ m^3 (920 acre ft)[a]
Existing freeboard	3.05 m (10 ft)[a]

Clear Water Pond	
Maximum storage pond area	20.6 ha (51 acres)
Normal storage pond area	20.6 ha (51 acres)
Existing storage volume	$1.0(10^6)$ m^3 (800 acre ft)[a]
Existing freeboard	3.05 m (10 ft)[a]

---

[a] These values will change as refuse is added to impoundment structures.

TYPE OF REFUSE AND PRIOR PROCESSING

Coal is mined from a seam approximately 229 m (750 ft) below the ground surface. Raw coal is processed in the preparation plant using a combination of froth flotation and heavy media procedures. The mine production rate averages 10,000 Mt/d (11,000 tpd) of raw coal. Approximately 15% of this is rejected. It is estimated that about 66% of the reject is coarse refuse and about 34% is fine. The reported coal chemistry at this facility is shown below.

		Met. Coal (%)	Steam Coal (%)
	Total moisture	11.5	12.0
	Volatile matter	36.1	35.0
Dry	Fixed carbon	58.1	53.0
Basis	Ash	5.8	12.0
	Sulfur	0.7	0.75
	Heat content	13,500 Btu	12,700 Btu

The reported water balance for the preparation plant is listed below:

To Plant	Cubic Meters/ Minute	Gallons/ Minute
Fresh water to all pump glands	0.29	78
Fresh water to all magnetic separators	1.67	440
Fresh water for makeup[a]	3.43	905
	5.39	1,423
From Plant		
With 1½ in. x 0 met. coal	0.23	62
With 3/4 in. x 1/2 mm steam coal	0.14	36
With 3 in. x 1/2 mm refuse	0.18	48
With 1/2 mm x 0 refuse	4.00	1,058
Evaporation	0.84	219
	5.39	1,423

---

[a] Makeup water is estimated at 60% from "C" pond and 40% from freshwater reservoir.

POLLUTION CONTROL CONSIDERATIONS

- The preparation plant recirculates slurry pond waters.
- Seepage out of the pond is retained by the small dam downstream from the dikes, and then is pumped back into the plant's water circuit.
- The dikes retaining the slurry pond are largely constructed of nonacid-producing coarse refuse.
- Due to the flat terrain, there is no runoff onto the site. Consequently, minimal dike erosion occurs.

IN THIS AERIAL VIEW, THE PREPARATION PLANT IS AT LEFT CENTER. PONDS EXTEND FROM THE PREPARATION PLANT TOWARDS THE UPPER RIGHT.

LOWER PORTION OF REFUSE DISPOSAL AREA, WITH ACTIVE SLURRY POND TO THE RIGHT. NOTE THE GENERAL FLATNESS OF THE TERRAIN.

SLURRY POND LIES TO LEFT OF THE EMBANKMENT AND CLEARWATER POND TO THE RIGHT. PREPARATION PLANT IS IN THE BACKGROUND.

CREST OF REFUSE DIKE RETAINING SLURRY POND. CREST WIDTH AT THIS POINT IS APPROXIMATELY 60 FT. REFUSE MOUNDS ALONG THE EDGES OF THE CREST ARE SAFETY BERMS INTENDED TO PREVENT TRUCKS FROM SLIPPING OFF.

TABLE A-33. SUMMARY OF WATER QUALITY DATA: SITE G
(Averages for four site visits)

	Sampling Point		
	1[a]	1-1/2[b]	2[c]
Parameter			
Flow (liter/min)	Standing	6	4.4
pH	8.21	7.85	8.1
Dissolved O_2 (mg/liter)	8.8	8.2	9.1
Acidity (mg/liter as $CaCO_3$)	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	184	190	382
Conductivity (umhos/cm)	1,433	2,310	5,908
Pollutant (mg/liter)			
Aluminum	2.0	8.2	1.9
Cadmium	0.002	--	0.007
Chloride	320	798	1,270
Copper	0.010	--	0.009
Ferrous iron	0.18	4	0.58
Total iron	2.21	7.40	2
Lead	0.007	--	0.013
Magnesium	4.6	9	20.8
Manganese	0.75	0.28	0.94
Mercury	<0.0001	<0.0001	<0.0001
Nickel	0.013	--	0.023
Sulfate	313	440	450
Zinc	0.02	0.11	0.05

---

a. Small pond on northwest corner of site.
b. Small seepage area near downstream toe of embankment.
c. Ditch parallel to one pond, upstream from point where it drains into pond for return to plant.

TABLE A-34. WATER QUALITY DATA: SITE G, SAMPLING POINT 1[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	Standing	None	Standing	Standing
pH	8.15	8.6	7.90	8.20
Dissolved O_2 (mg/liter)	--	8.8	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	163	190	193	190
Conductivity (umhos/cm)	1,200	1,330	1,400	1,800
Pollutant (mg/liter)				
Aluminum	2.2	1.2	0.53	4.1
Cadmium	0.001	--	0.002	0.004
Chloride	160	390	280	450
Copper	0.010	--	0.006	0.015
Ferrous iron	0.4	0.09	0.08	0.16
Total iron	2.36	1.35	0.22	4.90
Lead	0.015	--	0.004	0.003
Magnesium	3.5	4.5	5.3	4.9
Manganese	0.45	1.3	0.33	0.91
Mercury	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.002	--	0.006	0.032
Sulfate	200	240	300	510
Zinc	0.01	0.01	0.02	0.03

---

a. Small pond on northwest corner of site.

TABLE A-35. WATER QUALITY DATA: SITE G, SAMPLING POINT 1½[a]

	Sampling Date
Parameter	Sept 1976
Flow (liter/min)	6
pH	7.85
Dissolved O_2 (mg/liter)	8.2
Acidity (mg/liter as $CaCO_3$)	--
Alkalinity (mg/liter as $CaCO_3$)	190
Conductivity (umhos/cm)	2,310
Pollutant (mg/liter)	
Aluminum	8.2
Cadmium	--
Chloride	798
Copper	--
Ferrous iron	4.0
Total iron	7.4
Lead	--
Magnesium	9
Manganese	0.28
Mercury	<0.0001
Nickel	--
Sulfate	440
Zinc	0.11

---

a. Small seepage area near downstream toe of embankment

TABLE A-36. WATER QUALITY DATA: SITE G, SAMPLING POINT 2[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	2.5	10	1	4
pH	8.20	8.20	7.90	8.10
Dissolved O_2 (mg/liter)	--	9.1	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	508	314	284	420
Conductivity (umhos/cm)	7,200	3,830	5,600	7,000
Pollutant (mg/liter)				
Aluminum	1.6	4.0	0.41	1.5
Cadmium	0.008	--	0.002	0.010
Chloride	900	1,540	440	2,200
Copper	0.007	--	0.009	0.011
Ferrous iron	0.3	1.9	0.04	0.08
Total iron	1.33	3.91	0.36	2.4
Lead	0.031	--	0.002	0.007
Magnesium	15.3	14	30	24
Manganese	0.26	0.19	1.1	2.2
Mercury	<0.0001	<0.0001	<0.0001	<0.0004
Nickel	<0.001	--	0.056	0.011
Sulfate	510	520	300	470
Zinc	0.02	0.05	0.08	0.04

---

a. Ditch parallel to one pond, upstream from point where it drains into pond for return to plant.

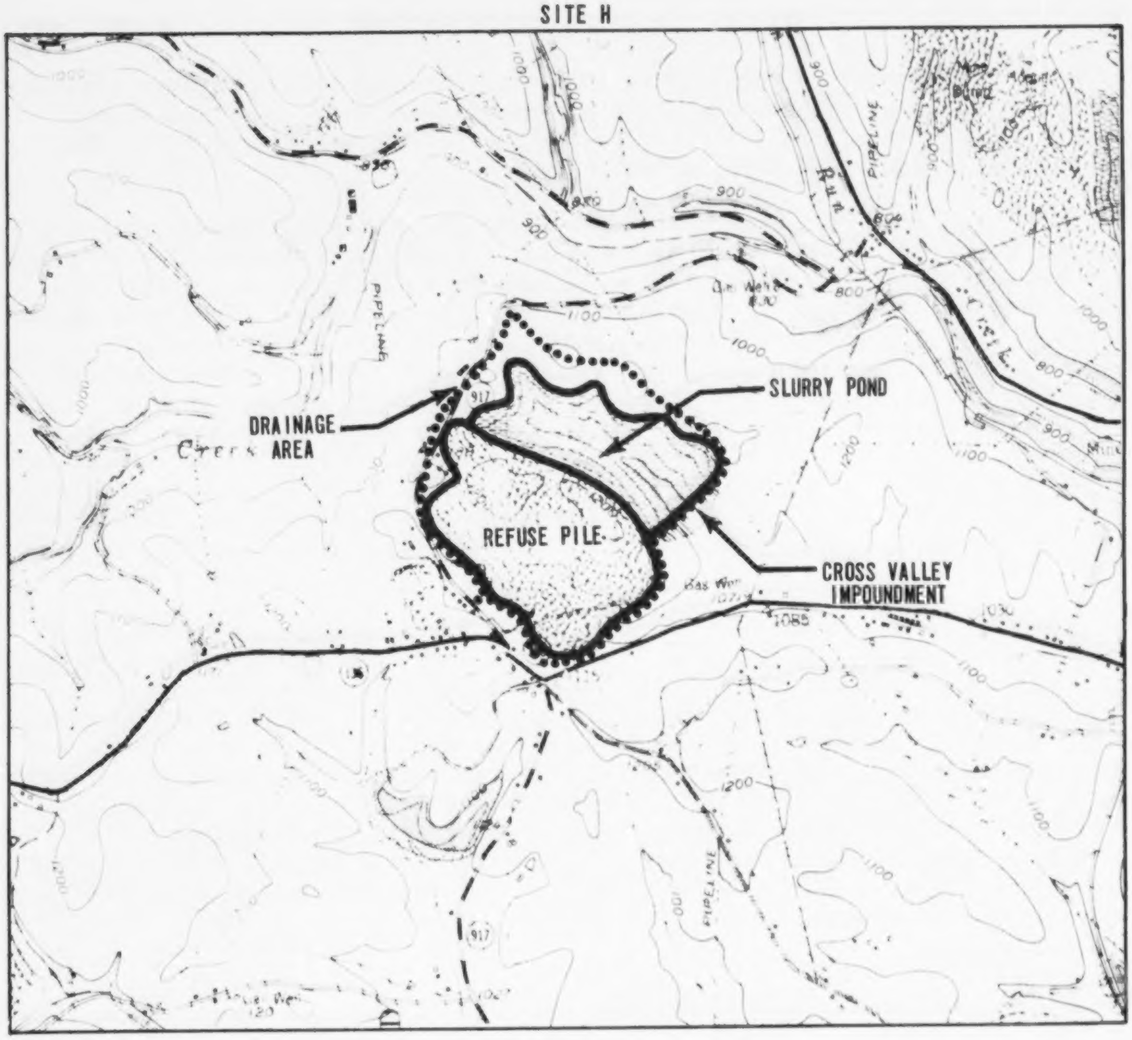
TABLE A-37. AIR QUALITY DATA: SITE G[a]

	Sampling Date				
	1/6/77	1/17/77	3/23/77	6/16/77	Average
Temperature (°C)	-4	-26 - -29	-1 - 4	15 - 18	
Weather Conditions	Light snow (3"-5"), ground frozen	Ground frozen, snow-covered	Ground wet, raining	Fair, ground damp	
Wind Speed (mps)	1.7	2.2 - 4.5	3.2	0.9 - 1.3	
Wind Speed (mph)	4	5 - 10	7	2 - 3	
Wind Direction	SSW	N+NW	W+NW	SW	
Dust/Particulates (mg/liter)	0.017	0.010	0.023	0.017	0.016
Gases (mg/liter)					
Nitrogen dioxide	0.015	<0.01	0.020	0.015	0.012
Sulfur dioxide	0.020	<0.01	0.040	0.020	0.020
Hydrogen sulfide	0.030	<0.03	<0.01	0.030	0.015
Carbon monoxide	1.5	1.3	1.5	1.5	1.5
Methane	3.0	2.9	3.5	3.0	3.1

---

[a] Sampling point corner of haulage road, far eastern corner of area.

SITE H


SLURRY POND
DRAINAGE AREA
REFUSE PILE
CROSS VALLEY IMPOUNDMENT
PIPELINE
Run
917
900
800
1000
1100
1200
1085

HYDROLOGIC DATA

Drainage Area: 43 ha (105 acres)
Precipitation (mean annual): 102 cm (40 in.)
Pond Evaporation (average annual): 76 cm (30 in.)
Temperature Extremes (Jan-July): Mean max. 6°C (42°F) to 29°C (85°F)
Mean min. -4°C (24°F) to 17°C (62°F)

Rainfall Design Frequencies: (24-hour storms)

	5-yr	10-yr	50-yr	100-yr
Depth, cm (in.)	8.4(3.3)	9.9(3.9)	12.2(4.8)	13.2(5.2)
Est. Storm Water Volume, m^3x10^3 (acre-ft)	35(28)	40(32)	49(40)	53(43)

SITE H: FEATURES AND OPERATIONS

Site H is in undulating terrain that has a maximum relief of approximately 76 m (250 ft). The refuse pile, located immediately upstream of the slurry pond, combines features of both valley-fill and ridge-type structures. The slurry pond is a cross-valley impoundment.

When the refuse pile was started in 1959, the area was cleared, grubbed, and stripped, and topsoil was stockpiled for future use in reclamation. Refuse is taken from the preparation plant by underground rail haulage, through nonproductive coal workings, to a point under the disposal area. From here it is skip-hoisted 107 m (350 ft) through a vertical shaft, at approximately 5.46 Mt/m (6 tpm), to a temporary storage bin. Two 32 Mt (35 ton) WABCO scrapers take the refuse from the bin to the disposal area, where it is placed in approximately 31 cm (12 in.) lifts and compacted by random routing of haulage equipment. Haul roads are maintained with a water truck and D-7 bulldozers. The surface of the refuse is sloped at approximately 2% to 3% into the slurry pond or into specially provided siltation basins. Side slopes are covered with clay soil and hydroseeded as the pile is raised. There is no history of fires in the refuse pile.

The slurry pond dam, constructed in 1959, has a central clay core with coarse refuse shells. The slopes were covered with soil and seeded. A concrete spillway is located on the left abutment and an outlet works near the right abutment. Slurry with an average of 35% solids is pumped from the preparation plant through a 13 cm (5 in.) pipeline at 1.04 - 1.13 m^3pm (275 - 300 gpm). The pipeline follows essentially the same route as the underground rail system which hauls the refuse. Near the pond the pipeline is brought to the surface through a vertical borehole, and the slurry is discharged into the southern portion of the impoundment. The solids settle in this portion of the pond and the clear water is decanted through the northern outlet works into a nearby tributary of a river.

DIMENSIONAL DATA

Refuse Area	
Surface area	40± ha (100± acres)
Maximum depth	30 m (100± ft)
Average surface slopes	2% to 3%
Average side slopes	2:1

Slurry Pond Embankment	
Crest length	610 m (2,000 ft)
Crest width	21 m (70 ft)
U/S slope	1:1
D/S slope	2:1
Max. vert. distance to foundation	30.5 m (100 ft)
Approximate volume	$9.95(10^5)$ m^3 (1,300,000 yd^3)

Slurry Pond	
Drainage area	43 ha (105 acres)
Normal storage	27 ha (66 acres)
Freeboard	3.7 m (12 ft)
Spillway	Concrete Chute
Outlet works	25-cm (10 in.) pipe

TYPE OF REFUSE AND PRIOR PROCESSING

The coal mined at Site H is from a seam which has an average thickness of 2 m (7 ft) and is located at a depth of 90 - 120 m (300 - 400 ft) below ground surface. This low-sulfur, high-volatile, metallurgical coal is mined by conventional room and pillar techniques, with full recovery in the retreat phase. Raw coal brought to the preparation plant is processed in three beneficiation systems: heavy media sand cone, concentrating table, and froth flotation. Approximately 10,900 - 12,700 Mt (12,000 - 14,000 tons) of raw coal are processed daily in the plant. Approximately 30% of this is reject. The ratio of coarse refuse to fine refuse is 8:1.

POLLUTION CONTROL CONSIDERATIONS

- A major portion of the drainage from the refuse pile is directed into the slurry pond.

- The pond has a flow-through water circuit; clarified waters are discharged into a nearby drainage area.

- Refuse from the preparation plant is brought to the disposal area through nonproductive, underground coal workings. This procedure eliminates the need for off-site, above-ground haul roads or conveyance systems.

- The completed embankment surface has been seeded to reduce erosion.

TABLE A-38. SUMMARY OF WATER QUALITY DATA: SITE H
(Averages for four site visits)

	Sampling Point		
	1[a]	1-1/2[b]	2[c]
Parameter			
Flow (liter/min)	0.62	533	2,538
pH	7.8	8.1	8.2
Dissolved O_2 (mg/liter)	10.4	10	10.2
Acidity (mg/liter as $CaCO_3$)	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	285	300	198
Conductivity (umhos/cm)	1,188	1,737	1,732
Pollutant (mg/liter)			
Aluminum	0.05	0.20	0.52
Cadmium	<0.001	<0.001	0.001
Chloride	169	73	136
Copper	0.001	0.001	0.002
Ferrous iron	0.03	0.03	0.07
Total iron	1.44	1.09	0.84
Lead	0.003	0.002	0.009
Magnesium	35	24	13
Manganese	0.50	0.76	0.36
Mercury	<0.0001	<0.0001	<0.0001
Nickel	0.002	0.008	0.001
Sulfate	280	923	718
Zinc	0.02	0.02	0.02

---

a. Small stream adjacent to site perimeter.
b. Overflow from main settling pond.
c. Downstream from confluence of main pond overflow and discharge of embankment drain system.

TABLE A-39. WATER QUALITY DATA: SITE H, SAMPLING POINT 1[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	0.5	0.5	0.5	1
pH	8.34	7.31	7.83	7.60
Dissolved O_2 (mg/liter	--	10.4	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	208	314	307	311
Conductivity (umhos/cm)	1,280	1,170	1,100	1,200
Pollutant (mg/liter)				
Aluminum	<0.01	0.02	0.09	0.06
Cadmium	<0.001	<0.001	0.001	<0.001
Chloride	--	248	120	140
Copper	0.001	0.001	0.001	<0.001
Ferrous iron	0.1	0.02	0.01	0.01
Total iron	5.24	0.02	0.05	0.47
Lead	0.005	0.001	<0.001	0.006
Magnesium	32.9	35	38	36
Manganese	1.9	0.04	0.02	0.02
Mercury	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.001	0.002	0.002	0.002
Sulfate	640	170	150	160
Zinc	0.05	0.01	0.01	0.02

---

a. Small stream adjacent to site perimeter.

TABLE A-40. WATER QUALITY DATA: SITE H, SAMPLING POINT 1½[a]

	Sampling Date		
	Sept 1976	Jan 1977	June 1977
Parameter			
Flow (liter/min)	910	50	640
pH	7.88	8.22	8.10
Dissolved O_2 (mg/liter)	10.0	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	237	385	280
Conductivity (umhos/cm)	1,810	1,100	2,300
Pollutant (mg/liter)			
Aluminum	0.29	0.16	0.14
Cadmium	<0.001	0.002	<0.001
Chloride	76	71	73
Copper	<0.001	0.007	<0.001
Ferrous iron	0.07	0.01	0.02
Total iron	1.76	0.31	1.2
Lead	0.002	0.003	0.001
Magnesium	26	26	20
Manganese	1.0	0.65	0.62
Mercury	<0.0001	<0.0001	<0.0001
Nickel	<0.001	0.004	0.018
Sulfate	940	730	1,100
Zinc	0.02	0.02	0.03

---

a. Overflow from main settling pond.

TABLE A-41. WATER QUALITY DATA: SITE H, SAMPLING POINT 2[a]

	Sampling Date			
	July 1976	Sept 1976	Jan 1977	June 1977
Parameter				
Flow (liter/min)	3,400	3,100	850	2,800
pH	8.38	7.96	8.17	8.10
Dissolved O_2 (mg/liter)	--	10.2	--	--
Acidity (mg/liter as $CaCO_3$)	--	--	--	--
Alkalinity (mg/liter as $CaCO_3$)	176	182	270	165
Conductivity (umhos/cm)	1,580	1,750	1,800	1,800
Pollutant (mg/liter)				
Aluminum	0.31	0.42	0.80	0.53
Cadmium	<0.001	0.001	0.003	0.001
Chloride	--	139	130	140
Copper	0.003	<0.001	0.004	0.002
Ferrous iron	0.1	0.14	0.01	0.03
Total iron	0.68	1.21	0.62	0.83
Lead	0.008	0.008	0.011	0.009
Magnesium	13.6	16	13	9.5
Manganese	0.3	0.54	0.33	0.26
Mercury	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	<0.001	<0.001	0.003	0.008
Sulfate	700	840	550	780
Zinc	0.03	0.01	0.02	0.02

---

a. Downstream from confluence of main pond overflow and discharge of embankment drain system.

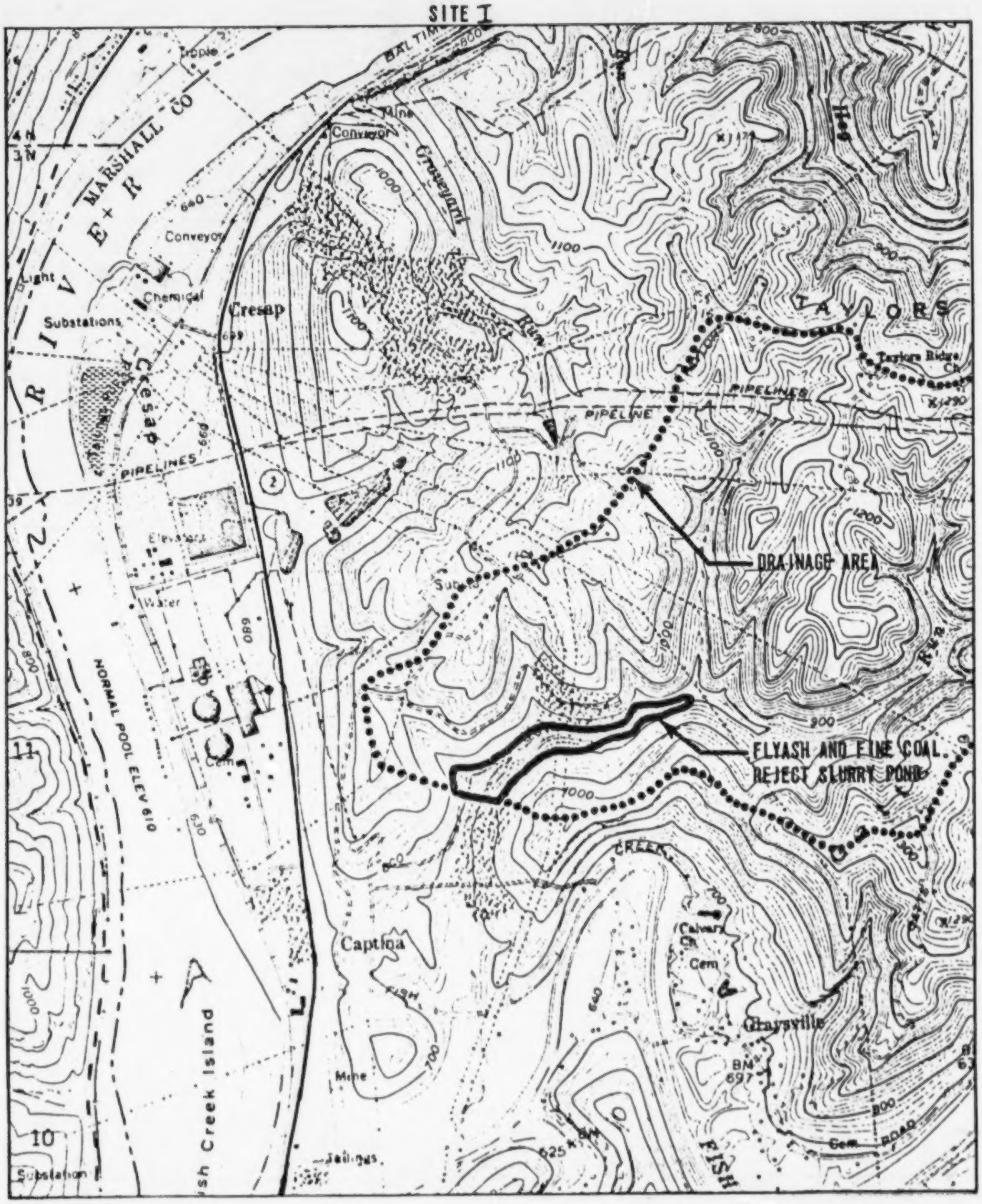
TABLE A-42. AIR QUALITY DATA: SITE H[a]

	12/30/76	1/21/77	5/18/77	6/22/77	Average
Temperature (°C)	-18 - -14	-26	27 - 29	21 - 28	
Weather Conditions	Cold, 2"-3" snow on ground	Very cold, snowing, 18" on ground	Hot, hazy	Clear, dry	
Wind Speed (mps)	2.0 - 2.2	3.6	1.0	0 - 0.8	
Wind Speed (mph)	4 - 5	8	2	0 - 2	
Wind Direction	S-SE	NW	SW	SW	
Dust/Particulates (mg/liter)	0.01	0.002	0.03	0.002	0.01
Gases (mg/liter)					
Nitrogen dioxide	0.077	0.01	0.028	0.028	0.033
Sulfur dioxide	0.001	<0.01	0.002	0.002	0.001
Hydrogen sulfide	0.003	<0.03	0.005	0.005	0.008
Carbon monoxide	1.8	1.4	1.5	1.1	1.4
Methane	3.2	3.0	3.5	3.0	3.2

---

[a] Sampling point 1/2 mile north of shaft.

SITE I

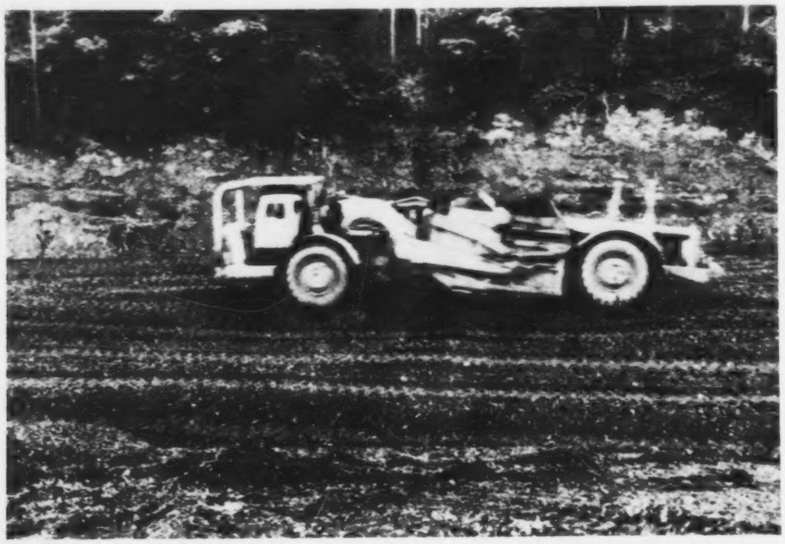

DRAINAGE AREA
FLYASH AND FINE COAL REJECT SLURRY POND
TAYLORS
Taylors Ridge Ch
PIPELINES
PIPELINE
MARSHALL CO
RIVER
Graveyard Run
Cresap
Conveyor
Mine
Tipple
Chemical
Substations
Light
Elevators
Water
NORMAL POOL ELEV 610
Fish Creek Island
Captina
Calvary Ch
Cem
Graysville
BM 697
FISH CREEK
ROAD
Tailings
Substation
1000
1100
1200
900
11
10

SITE I: FEATURES AND OPERATIONS

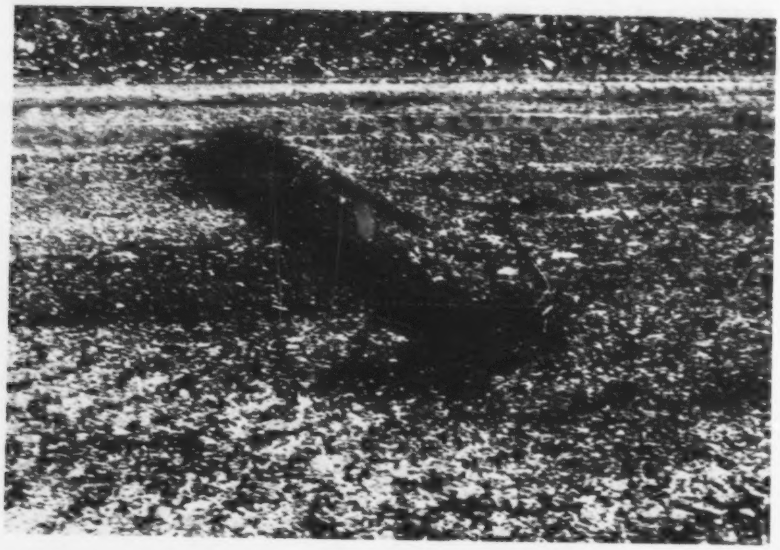
Site I is an engineered embankment designed and developed primarily for disposal of flyash from nearby power generating plants. However, coarse coal refuse from neighboring mines is currently being utilized to raise the main embankment. The refuse is delivered by scrapers to the portion of the embankment being raised, where it is spread, compacted, and leveled by equipment operated by the utility company. The utility needs large amounts of fill to raise the flyash retention dam, so that if the coarse coal refuse was not available an equal amount of native borrow material would be required. This would create an environmental condition equivalent to that from an open-pit mining operation.

Fine coal refuse in slurry form is discharged into the upper end of the pond. The coarse coal refuse is used for bank fill and coarse boiler slag is used to construct the drain zones of the embankment. The drain material is placed not only as a vertical drain to intercept seepage through the impervious upstream face of the dam, but also along the downstream foundation area and the abutment contacts to intercept natural seepage water. Interception of pond and underground waters permits a controlled flow of this water and prevents its potential contamination by the coal refuse. In addition, from an engineering viewpoint, control of the seepage waters is necessary for structural stability.

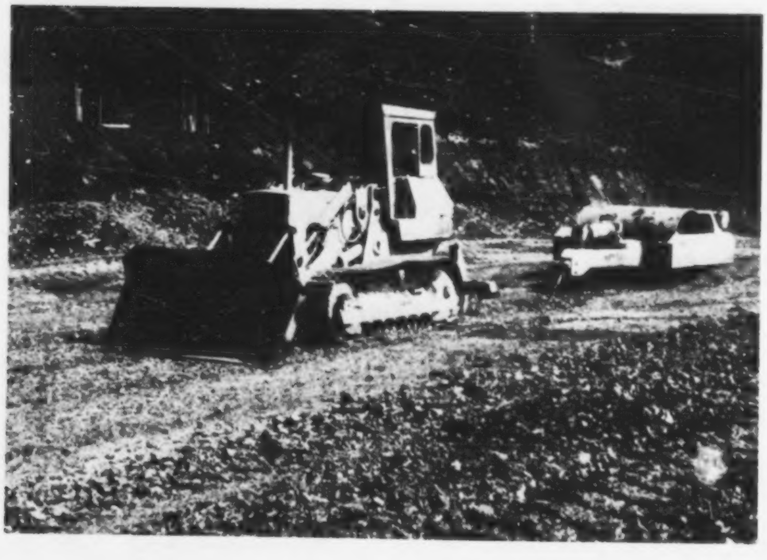
ZONING OF RETAINING DAM. COARSE REFUSE IS TO THE RIGHT, AND THE NATURAL SOIL/ROCK ABUTMENT TO THE LEFT. THE DARK LAYER SEPARATING THE TWO ZONES IS A PERMEABLE BOILER SLAG FROM A NEARBY POWER PLANT.



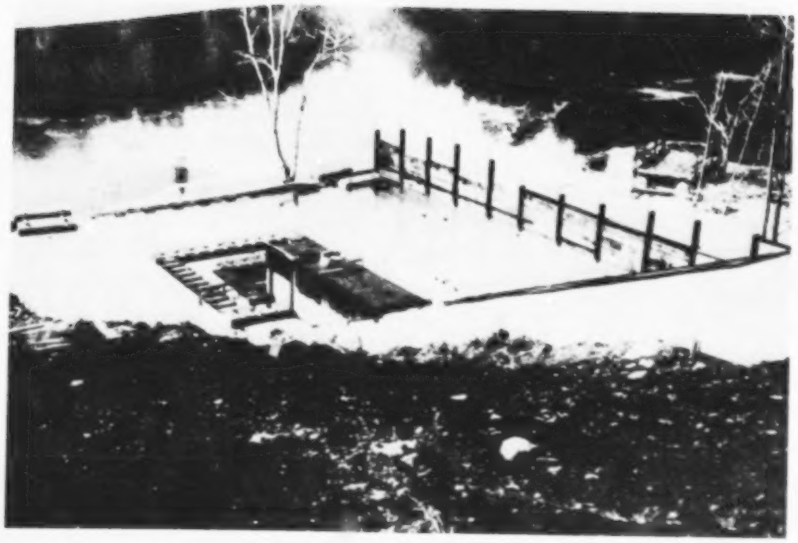
TWIN-ENGINED SCRAPER PLACING REFUSE NEAR DAM ABUTMENT. NOTE THAT THE SCRAPER IS PLACING THE REFUSE IN VERY THIN LIFTS. THE USE OF THIN LIFTS IMPROVES THE TRAFFICABILITY OF THE REFUSE SURFACE.



WEIGHTED LEVELING BOARD WHICH IS PULLED BEHIND A BULLDOZER TO PROVIDE A SMOOTH, LEVEL SURFACE FOR THE VIBRATORY COMPACTOR.



BULLDOZER AND HEAVY VIBRATORY ROLLER USED TO GRADE AND COMPACT COARSE REFUSE IN DAM EMBANKMENT.



CLEARWATER DECANT STRUCTURE IN SLURRY POND. OUTER FENCE AND LOG BOOM KEEPS OUT FLOATING LARGE BRUSH AND LOGS. SMALLER FLOATING BOOM NEAR THE STRUCTURE PREVENTS THE FINE PORTION OF THE FLYASH WASTE FROM BEING DECANTED INTO THE DOWNSTREAM RIVERS.

APPENDIX B

FIELD AND LABORATORY TESTS USED TO DETERMINE REFUSE PROPERTIES

It is advantageous to have a standard method of identifying soils and categorizing them according to their engineering properties. In 1952, the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers, with Professor Arthur Casagrande of Harvard University as consultant, agreed on a modification of Professor Casagrande's airfield classification system for soils which they termed the "Unified Soil Classification System" (USCS). This system, which is particularly applicable to the design and construction of dams and impoundments, takes into account the engineering properties of the soils, is descriptive and easy to associate with actual soils, and is adaptable to both field and laboratory testing programs. Probably its greatest advantage is that a soil can be classified readily by visual and manual examination without the need for costly laboratory testing.

The USCS is based on particle size, amount and distribution of the various sizes, and material plasticity. Soils are divided into coarse-grained, fine-grained, and highly organic (peaty) soils.

FIELD TESTS

A number of field tests can be performed in order to determine certain physical properties of coal refuse materials. The type and number of field tests and program sequence depends on whether the results are needed for an assessment of a potential borrow source, for an ongoing program of construction control, or for an investigation of a completed dam or impoundment to determine its condition.

Moisture and Density

In-place determinations of moisture and density or unit weight are usually made using the American Society for Testing and Materials (ASTM) Test Method D-1556. This method involves excavating a hole from a horizontal surface, weighing the excavated material, and determining the volume of the hole by filling it with a sand of known density. A water content determination of the excavated sample makes it possible to calculate the dry density in the ground. Various devices using balloons and water or soil have been used to measure hole volume, but the sand method is most common.

Depending on the maximum and average particle sizes of the material being tested, the size of the test hole and therefore the type of equipment to be used will vary. For example, field density tests of pervious materials containing particles more than 2 inches in size are usually made using the water-volume method. This method, which requires the use of a 3-foot- or 6-foot-diameter ring, has not yet been standardized by ASTM, but has been used as a means of control on important earth dam projects (for example Oroville Dam, the highest earthfill dam in the United States). The tabulation below shows the minimum desired test hole volume, depending on the average gradation characteristics of the material being tested.

Minimum Test Hole Volumes and Minimum Moisture Content Samples
(based on maximum particle size)

Maximum Particle Size	Minimum Test Hole Volume (ft^3)	Content Sample (gm)
No. 4 sieve (4.75 mm)	0.025	100
1/2 inch (12.5 mm)	.050	250
1 inch (25 mm)	.075	500
2 inch (50 mm)	.100	1,000
Greater than 2 in.	8 - 15 (water-displacement method)	--

Density tests are usually performed in backhoe pits, dozer pits, or other types of excavations. Care should be taken to test representative areas and, if the test location has been prepared using motorized equipment, the test level should be at least 1 foot below the surface of excavation, to minimize any disturbing influences of the excavating equipment. Extreme care should be exercised in performing tests in any type of exploratory pit because the side walls may be subject to instability or collapse. Federal safety standards should always be observed when people are working in unsupported trenches.

Shear Strength

There are several methods for conducting in-situ shear strength tests. The vane shear test, which is the most commonly used method, shows little or no promise for coal refuse testing because of the grain size and characteristics of these materials. The vane shear has been used in attempts to determine in-situ shear strength of fine-grained sludge materials, but these materials have nonplastic characteristics and therefore tend to dilate when sheared in an undrained condition. Static cone penetrometers, such as the Dutch Cone device, have been increasingly popular in the United States in recent years. Much research is needed, however, to correlate penetration resistance and sleeve friction ratios with variations in density and shear strength before the Dutch Cone device can be successfully used for coal refuse testing. Standard penetration (dynamic) tests have been used to determine the relative density of coarse-grained, nonplastic mateials, with generally adequate results. This method more properly indicates the uniformity or lack of uniformity of a deposit, rather than directly indicating the shear strength.

Permeability

As used by soils engineers, the coefficient of permeability is the superficial velocity of water as it passes through a soil under a unit gradient. The value of the coefficient of permeability reflects the ease with which water will flow through a soil, and this must be known in order to calculate the quantity of flow. The range of permeability for soils is extremely great--from more than 1 cm/sec (1,000,000 ft/yr) for clean gravels to 10^{-8} cm/sec (0.1 in./yr) or less for clays.

Approximate values of permeability can be obtained by field testing. The reliability of the values obtained depends on the homogeneity of the stratum tested and on certain restrictions of the mathematical formulas used. If reasonable care is exercised in adhering to the recommended procedures (for example U.S. Bureau of Reclamation Test Method E-18), useful results can be obtained.

The two methods of determining the coefficient of permeability that are used most often in the field are the infiltration, or pumping-in, test and the pumping-out test. In the first method, water is introduced into a drill hole or test pit of known dimensions, and the rate of seepage under a fixed or variable head is observed. The second (and less used) method involves drawing out water at a constant rate from a drill hole and observing the rate of drawdown of the water table in observation wells placed in a geometric pattern, usually radial, at various distances from the point of water withdrawal. Test data must be interpreted on the basis of simplified formulas or flow net analyses with application of proper judgment regarding geological factors such as channeling, layering, and the anisotropic characteristics of deposits.

LABORATORY TESTS

Laboratory tests are usually performed on three types of samples.

- Undisturbed tube samples obtained with special sampling equipment using a drill rig and undisturbed hand-cut block samples.

- Disturbed samples, such as standard penetration samples, bulk samples, or drill cuttings.

- Compacted samples fabricated to represent materials of known characteristics.

The hand-cut sample is rarely needed unless the material is very sensitive to standard sampling procedures or has a minor geologic feature which may be obscured or otherwise destroyed in the sampling process.

Good-quality undisturbed samples are needed if engineering properties of in-situ materials are to be obtained by laboratory testing. Special field techniques are needed to obtain undisturbed samples and, once they are obtained, care should be exercised in transporting them to the laboratory. Compacted or fabricated samples are prepared to represent soils with known moisture, density, and structural characteristics. These samples can be used in lieu of undisturbed samples of materials, such as clean sand, which cannot be sampled and transported without changes in density. Since the in-situ characteristics can be measured, the loose materials can be fabricated into samples that represent undisturbed conditions. These types of samples can also be used to test the characteristics of man-made or compacted materials.

Classification Tests

Tests required for USCS classification in the laboratory include gradation and Atterberg limits tests.

Gradation. The gradation or grain size analysis of soils is performed in accordance with ASTM D-422 and D-1140, which involve dry sieving for materials coarser than the #200 sieve and hydrometer analysis for materials finer than the #200 sieve. The results are presented in the form of percent of the total sample passing (based on dry weight) a given size sieve.

Atterberg Limits. A typical soil mass has three constituents: soil grains, air, and water. In soils consisting largely of fine grains, the amount of water in the voids has a pronounced effect on soil properties. Three main states of soil consistencies are recognizable:

- Liquid state, in which the soil is either in suspension or behaves like a viscous fluid

- Plastic state, in which the soil can be rapidly deformed or molded without rebounding elastically, changing volume, cracking, or crumbling

- Solid state, in which the soil will crack when deformed or will exhibit elastic rebound

In describing these soil states, it is customary to consider only the fraction of soil smaller than the #40 sieve (the upper limit of the fine sand component). For this soil fraction, the water content in percentage of dry weight at which the soil passes from the liquid state into the plastic state is called the Liquid Limit (LL). A device which causes the soil to flow under certain controlled conditions is used in the laboratory to determine the LL.

The water content of the soil at the boundary between the plastic state and the solid state is called the Plastic Limit (PL). The laboratory test used to define this limit consists of repeatedly rolling threads of soil to 1/8-inch diameter until they crumble, and then determining the water content. The difference between the LL and the PL corresponds to the range of water contents within which the soil behaves plastically. This difference of water content is called the Plasticity Index (PI). Highly plastic soils have a high PI value. In a nonplastic soil, the PL and the LL are the same, and the PI equals 0. These limits of consistency, which are called Atterberg limits, are used in the USCS as the basis for laboratory differentiation between materials of appreciable plasticity (clays) and slightly plastic or nonplastic materials.

Moisture-Density

The natural or in-place density and water content of a sample obtained in the field are determined in the laboratory by carefully extruding the sample from its container, measuring its natural weight and dimensions, and placing the material in an oven at a controlled temperature to evaporate all retained water. Coal refuse materials present a special problem, because they contain combustible material (such as minor amounts of coal) that will burn at temperatures below the recommended temperature (110°C) of ASTM D-2216, the applicable standard for determining the moisture content of soils. W. A. Wahler & Associates has found, by trial and error, that a drying temperature of 30°C ± 3° for a period of 48 hours is appropriate for coal refuse materials.

Once the dry weight of the material is determined, the total and dry unit weight (density) and water content are determined using the following formulas:

$$w = \frac{W_w - W_d}{W_d} \times 100$$

$$\gamma_t = \frac{W_w}{V}$$

$$\gamma_d = \frac{W_d}{V}$$

where

W_w = wet weight of total sample in pounds

W_d = dry weight of total sample in pounds

V = volume of total sample in cubic feet

w = water content, based on dry weight, in percent

γ_t = total unit weight of material, usually expressed in pounds per cubic foot

γ_d = dry unit weight of material, usually expressed in pounds per cubic foot.

Specific Gravity

Specific gravity is defined as the ratio of the weight in air of a given volume of a material at a stated temperature to the weight of an equal volume of distilled water at a stated temperature. The specific gravity for material finer than the #4 sieve is determined in accordance with ASTM D-854; for materials predominantly larger than the #4 sieve, it is determined in accordance with ASTM C-127. The specific gravity of a material must be known or assumed in order to calculate the void ratio and percent of saturation of a given material. The following formulas relate void ratio, specific gravity, saturation, water content, and dry unit weight:

$$e = \frac{G\gamma_w}{\gamma_d} - 1$$

$$S = \frac{wG}{e}$$

where

e = void ratio

G = specific gravity

γ_d = dry unit weight of soil

γ_w = unit weight of water

S = Saturation in percent

w = water content based on dry weight, in percent

Compaction and Relative Density

Soil moisture-density relationships are determined in the laboratory in accordance with ASTM D-1557. The prescribed method covers the determination of density when the material is compacted in a mold of a given size using a 10-pound hammer dropped from a height of 18 inches. Four methods are provided:

Method A - a 4-inch-diameter mold with material passing the #4 sieve.
Method B - a 6-inch-diameter mold with material passing a #4 sieve.
Method C - a 4-inch-diameter mold with material passing a 3/4-inch screen.
Method D - a 6-inch-diameter mold with material passing a 3/4-inch screen.

The method to be used should be indicated in the specifications for the material being tested. If no method is specified, Method A is usually used.

The energy imparted using these procedures is equal to 56,250 ft-lb/ft^3 and was originally established as a means of laboratory control for airfield construction where heavy compaction equipment was required. The earth dam field, primarily through the work of the State of California Department of Water Resources, has adopted a lighter compaction standard to more realistically reflect the compaction effort likely to be achieved in the field. This standard, which is used by W. A. Wahler & Associates, is a compactive energy equal to 20,000 ft-lb/ft^3. The 10-pound hammer falling 18 inches is also used in this test; therefore, when testing under Method A with a 4-inch-diameter mold, the number of blows per layer is reduced from 25 to 15 and the number of compacted layers is reduced from 5 to 3.

For materials with up to about 12% passing the #200 sieve, water will not act as a lubricant in the compaction process and a well-defined moisture-density relationship cannot be developed. For these soils, the compaction standard used is ASTM D-2049, which utilizes vibratory equipment. The results are in the form of maximum and minimum densities; in general, the maximum density values obtained using vibratory methods are greater than those using impact methods.

Relative density is defined as the state of compactness of a soil with respect to the loosest and densest states at which it can be placed using the ASTM D-2049 laboratory procedures. It is expressed as the ratio of the difference between the void ratio of a cohesionless soil in the loosest state and the given void ratio to the difference between its void ratios in the loosest and densest states. The mathematical expression for this definition is:

$$D_d = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

where

D_d = relative density of field sample in percent

e_{max} = the void ratio corresponding to the loosest laboratory density

e_{min} = the void ratio corresponding to the most compact laboratory density

e = the void ratio corresponding to the field density

Permeability

The fundamental property involved in fluid flow is permeability. Because soil permeability depends very much on the arrangement of individual particles, and because of the difficulty associated with obtaining representative samples, field determinations are often required in order to determine average permeability. However, since laboratory determinations are much easier to make than field determinations and permit study of the relationship of permeability to void ratio, laboratory tests are usually performed regardless of whether field measurements are made.

Among the methods used in the laboratory to determine permeability are falling (or variable) head permeameter and constant head permeameter tests, and direct or indirect measurements from consolidation tests. For relatively free-draining material with less than 10% passing the #200 sieve, the coefficient of permeability should be determined in accordance with ASTM D-2434, which uses a constant head method. For materials with more than 10% passing the #200 sieve, saturation can have a marked effect on the results (some materials exhibit a coefficient of permeability 100% greater at a saturation of 100% than at a saturation of 80%), and it is suggested, therefore, that a testing procedure be used that will ensure that the sample is completely saturated before the permeability test is performed.

The permeability of fine-grained materials can be determined from the results of one-dimensional consolidation tests using the following relationships:

$$k = \frac{c_v a_v \gamma_w}{1 + e}$$

where

c_v = coefficient of consolidation

a_v = coefficient of compressibility

γ_w = unit weight of water

e = void ratio

Consolidation

Applying stress to a material causes strains. In materials such as clays and silts, or sands and gravels that contain sufficient quantities of clays and silts, a certain time is required for strain to occur. In such materials, the stresses, strains, and time bear definite relationships to each other; these relationships are mechanical properties of the material, and are called stress-strain-time relationships. The stress-strain-time relationship (or consolidation characteristics of a soil) are determined in accordance with ASTM D-2435. Two soil properties are determined from the one-dimensional consolidation tests: C_c, the compression index, which is used to calculate the magnitude of the settlement, and c_v, the coefficient of consolidation, which is used to calculate the rate of settlement.

Critical Hydraulic Gradient

The critical hydraulic gradient is defined as the gradient that occurs with upward flow of water through soils which causes the effective stress to be reduced to zero. If this persists in the field, the zone within which it occurs has no ability to resist shearing stresses ("quick" condition), and this could result in a progressive shear failure.

The theoretical expression for critical gradient is:

$$i_{cr} = \frac{G - 1}{1 + e}$$

where

i_{cf} = critical gradient

G = specific gravity of material

e = void ratio

A simple laboratory test to verify this expression can be performed on fine coal refuse by compacting the material in small (less than 4-inch-diameter) lucite cylinders to the average dry density observed in the field. The materials are then saturated and a head of water is imposed in order to cause water to flow upward through the soil column. The head is gradually increased until the soil column becomes buoyant or a blowout (water above the soil column suddenly turns black) occurs. The critical gradient is calculated as the difference in total head (tailwater-headwater) divided by the height of the soil column.

Shear Strength

The evaluation of soil shear strength is essential for the determination of dam or impoundment safety. Shear strength cannot be estimated from the angle of repose but must be physically measured in the field or laboratory.

The shear strength of soil and particulate rock materials is given by the Mohr-Coulomb Failure Law* as:

$$s = \bar{\sigma} \tan \phi' + c'$$

where

s = shear strength

$\bar{\sigma}$ = effective normal stress

ϕ' = angle of internal friction as determined by effective stress

c' = cohesion as determined by effective stress

Direct Shear Test. The shearing resistance of soils can be determined using a simple shear box wherein a soil sample is confined by a normal pressure and the force developed during shear testing is measured. The advantages of this method are that it is relatively uncomplicated and the equipment is not expensive. The disadvantages are that failure is forced to occur on a horizontal plane, the test must be run in a drained condition, and if conventional equipment is used, the maximum particle size should be limited to about 1/4 inch.

Triaxial Test. Determination of shear strength by means of triaxial testing requires extensive knowledge and experience. Test results can be influenced by many factors, including size of sample, method of sampling, degree of saturation, rate of strain, rate and method of load application, drainage conditions, and method of failure interpretation. Testing procedures are usually identified with a three-letter designation:

First letter - defines how the stresses are applied to the sample

I - Isotropically consolidated prior to application of shearing force

A - Anisotropically consolidated prior to application of shearing force

---

*Conventional shear strength theory is based on work originated by the French mathematician Coulomb in 1776 and extended by Otto Mohr, who first wrote about general strength theory in 1882.

Second letter - indicates whether the sample was consolidated or unconsolidated prior to application of the shearing force

U - Unconsolidated

C - Consolidated

Third letter - defines the drainage conditions which existed during application of the shearing force

U - Undrained

D - Drained

The four most commonly used triaxial tests are:

IUU - Isotropically Unconsolidated Undrained
ICU - Isotropically Consolidated Undrained
ICD - Isotropically Consolidated Drained
ACU - Anisotropically Consolidated Undrained

The triaxial test results are interpreted by the use of the Mohr circle of stress at some point during the progress of the test. Three types of failure criteria may be used to interpret the test results; the actual method selected will depend on material type and on the type of analysis the results are to be used for:

Maximum Obliquity - maximum ratio of major to minor principal stresses during shear

Maximum Deviator Stress - major and minor principal stresses occurring at the point of maximum deviator stress

Specific Percent Strain - major and minor principal stresses occurring at some specific percent axial strain

Dynamic Triaxial Test. The discussion on triaxial testing also applies to the evaluation of shear strength under static loading conditions. If the stability of a dam or impoundment is to be evaluated under earthquake loading conditions, the shear strength under dynamic loading conditions should be evaluated. The testing procedures described above for the static test are used in the dynamic test, except that after the sample has been consolidated by either isotropic or anisotropic means, it is failed by applying cyclic, rather than static, loads. For a given consolidation stress, tests of several samples will be required in order to define the influence of cyclic stress magnitude and the corresponding number of load applications required to cause failure. Failure may occur, depending upon the type of material, as the result of liquefaction or excessive axial strain. Whereas only 3 samples are necessary for an adequate determination of static shear strength, 12 to 24 samples may be required for an adequate determination of dynamic shear strength characteristics.

Unusual Testing Problems

Since coal refuse materials differ from those commonly used in embankment construction in that coal refuse may have a rather high carbon content, the potential for burning should be determined by means of ignition point tests. The results may influence disposal facility if there is a major requirement for ignition prevention. Generally, coarse and fine sludge materials can be tested using the soil materials tests discussed above. Except for some sample fabrication difficulties associated with loose or unconsolidated materials (particularly in the case of the dry, cohesionless "red dog"), no great difficulties in testing are likely to be encountered.

GLOSSARY OF RELEVANT GEOTECHNICAL TERMS

Abutment--the point of contact between the ends of an embankment and the natural ground material.

Acre-foot--a term used in measuring water volume, equal to the quantity required to cover 1 acre 1 foot deep, or 43,560 ft^3.

Angle, flare--the angle between the centerline of a structure and a wall.

Angle, friction--the angle measured from the abscissa which defines the limiting stress equilibrium between normal stress (effective or total) and shear stress (the ordinate).

Apron--A floor or lining of concrete, timber, or other resistant material at the toe of a dam, bottom of a spillway, chute, etc., to prevent erosion from falling water or from turbulent flow.

Area, discharge--The cross-sectional area of a waterway.

Area, drainage--The area tributary to a lake, stream, sewer, or drain. Also catchment area, watershed, and river basin.

Backfill--The operation of refilling an excavation. Also the material placed in an excavation in the process of backfilling.

Basin, stilling--(1) A structure or excavation which reduces velocity or turbulence of flowing or falling water.

(2) A structure at the outlet end of a spillway to partially dissipate the energy of flowing water and discharge the water into the downstream channel in such a manner as to prevent damage to the dam or dangerous scour to the banks of the channel.

Bedrock--Any solid rock underlying soil, sand, clay, silt, etc.

Berm--A horizontal strip or shelf built into an embankment or cut to break the continuity of an otherwise long slope, usually for the purpose of reducing erosion, or to increase the thickness or width of cross section of an embankment. Also the space left between the upper edge of a cut and the toe of an embankment.

Capacity, flood storage--That portion of the reservoir capacity which is reserved for the temporary storage of flood waters to reduce downstream peak flows.

Coefficient of permeability--The rate of flow of a fluid through a unit cross section of a porous mass under a unit dydraulic gradient, at a temperature of 60°F.

Cohesion--The state or process by which the particles of a body or substance are bound together, due to the force of attraction between the molecules.

Conduit--A general term for an artificial or natural duct, either open or closed, for conveying water or other fluids.

Core, impervious--The central portion of an embankment designed and constructed to prevent the passage of water.

Creep--The movement of water under or around a structure built on permeable foundations.

Creep, soil--The slow movement, usually over relatively short distances, of a mass of soil acting under the force of gravity. The term is usually applied to such a phenomenon when it is much smaller in magnitude and extent than a landslide.

Crest--The top of a dam, dike, spillway, or weir, to which water must rise before passing over the structure. It is frequently restricted to the overflow portion.

Culvert--A closed conduit for the free passage of surface drainage water under a highway, railroad, canal, or other embankment.

Dam--A barrier constructed across a watercourse for the purpose of creating a reservoir, diverting water therefrom into a conduit or channel, generating power, or for retention of debris.

Dam, starter--Initial embankment utilized to create a tailings pond and which becomes the foundation upon which the main dike is raised.

Dam, toe--(1) The downstream edge at the base of a dam.

(2) The line of a fill slope where it intersects the natural ground, and the lowest edge of a backslope of a cut where it intersects the roadbed.

Delta--An alluvial deposit formed where a stream drops its debris load on entering a body of quieter water; the terminal deposit of a river.

Dike--(1) An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of low lands or to deflect water away from a bank.

(2) An embankment constructed to retain water in a reservoir. The term dam is usually used where the structure is constructed across a watercourse or stream channel, and dike where it is constructed solely on dry ground.

(3) A vertical or steeply inclined wall of igneous rock, which has been forced into a fissure in a molten condition, and there consolidated. Dikes usually obstruct the passage of ground water.

Drainage tile--The removal of surplus ground water by means of buried pipes. Water enters through the unsealed joints or through perforations in the pipe.

Drain pipe--Pipe, usually perforated plastic, which discharges water collected from a drain zone.

Drain zone--An area within a zoned dam which collects and transmits seepage water. Usually constructed of coarse gravel.

Erodibility--The relative ease with which one soil erodes under specified conditions of slope as compared with other soils under the same conditions.

Erosion--Wearing away of land or structures by running water, glaciers, winds, and waves.

Fill--(1) Depth to which material is to be placed (filled) to bring the surface to a predetermined grade; therefore, fill is the difference in elevation between a surface point and a point vertically above it at the proposed grade.
(2) The volume of material to be added.
(3) An embankment.

Fill, hydraulic--An adjective applied to an earth structure or grading operation in which the fill material is transported and deposited in place by means of water pumped through a pipe line.

Filter--A device or structure for removing solid or colloidal material, usually of a type that cannot be removed by sedimentation from water, sewage, or other liquid. The liquid is passed through a filtering medium, which may consist of a granular material such as sand, infusorial, or diatomaceous earth, anthracite coal, etc., finely woven cloth, unglazed porcelain, or specially prepared paper.

Flood, maximum possible--The largest flood that theoretically can occur at a given site during present geologic and climatic era, assuming simultaneous occurrence of all possible flood producing factors in the area.

Flood, maximum probable--The maximum flood for which there is a reasonable chance that it will occur on a given stream at a selected site. It is often assumed to be equal to the maximum flood observed in areas having the same or similar physiographic and meterological characteristics. Such a flood would very likely be less than the maximum possible flood.

Flood, 10-year (or other designated period)--The flow of a stream which has been equaled or exceeded, on the average, once in 10 years (or other designated period).

Flow net--A graphical representation of second-order differential equations used to determine quantity of flow and water pressures.

Freeboard--The vertical distance between the normal maximum level of the surface of the liquid in a conduit, reservoir, tank, canal, etc., and the top of the sides of an open conduit, the top of a dam or levee, etc., which is provided so that waves and other movements of the liquid will not overtop the confining structure.

Frequency--(1) The time rate of vibration or the number of complete cycles per unit time.

(2) A term used to denote the number of times a certain phenomenon occurs in a given time.

(3) The number of occasions that the same numerical measure of a particular quantity has occurred between definite limits.

Gradation--A term used to describe the series of sizes into which a soil sample can be divided.

Gradient--(1) The rate of change of any characteristic per unit of length, or slope. The term is usually applied to such things as elevation, velocity, pressure, etc.

(2) The change in a variable quantity, as temperature or pressure, per unit distance; also a curve representing such a rate of change.

Grain size--Physical size of soil particle, usually determined by either sieve or hydrometer analysis.

Ground water--Subsurface water occupying the saturation zone, from which wells and springs are fed. In a strict sense the term applies only to water below the water table.

Intake--(1) The place where water enters a conduit or other structure.

(2) The works or structures at the head of a conduit or canal into which water is diverted.

(3) The process or operation by which water is absorbed into the ground and added to the zone of saturation.

Launder--(1) A trough, channel, or gutter, by which water is conveyed.

(2) In mining, a chute or trough for conveying powdered ore, or for carrying water to or from the crushing apparatus.

Method, rational--a method of estimating flood flows which will occur from the drainage basin above any point. For each subdivision of the drainage area the quantity of rainfall which will probably occur during the time of concentration, the percentage of rainfall which will appear as the surface runoff, and the time required for such flow to reach the point in question are estimated for various subdivisions of the drainage area, and from these the flow at the point in question is determined.

Outlet--(1) Downstream opening or discharge end of a pipe, culvert, sewer, or canal.

(2) Opening near the bottom of a dam for draining the reservoir.

(3) Lateral escape which spills over a natural bank into a depression or basin.

Permeability--The property of a material which permits appreciable movement of water through it when saturated and actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water. The rate of permeability is measured by the quantity of water passing through a unit cross section in a unit time when the gradient of the energy head is unity.

Piping--The action of water passing through or under a dam and carrying with it to the surface at the downstream toe some of the finer material. Such action may result in excessive leakage or even failure, as with the increased porosity of the material due to removal of the fines, the velocity of the water increases and in turn more and larger-sized material is removed.

Pond--(1) a Body of water of limited size either naturally or artificially confined and usually smaller than a lake.
(2) To gather together into a pond.

Pore--As applied to stone, soil, etc., any small interstice or open space, generally one that admits the passage or adsorption of liquid or gas.

Porosity--(1) The state of being porous or containing insterstices.
(2) An index of the void characteristics of a soil or stratum as pertaining to percolation; degree of perviousness.

Pressure, pore water--Interstitial pressure acting within the water or air contained in the void space of soil or rock.

Rain, heavy--Rain which is falling at the time of observation with an intensity in excess of 0.30 in./hr.

Rate, percolation--The rate, usually expressed as a velocity, at which water moves through saturated granular material. The term is also applied to quantity per unit of time of such movement, and has been used erroneously to designate infiltration rate or infiltration capacity.

Red dog--General term applied to ash-like residue remaining after a coal waste dump has burned.

Riprap--(1) Broken stone or boulders placed compactly or irregularly on dams, levees, dikes, etc., for protection of earth surfaces against the action of waves or currents.
(2) Brush or pole mattresses, or brush and stone, or other similar materials used for protection.

Runoff, storm--That portion of the total runoff from storm rainfall or rapid snow melt which reaches the point of measurement within a relatively short period of time subsequent to the occurrence of the rain or thaw.

Safety, factor of--The ratio of the forces tending to resist embankment failure to the forces tending to cause such failure. Thus any factor of safety less than 1.0 indicates an unstable condition.

Saturation--(1) Completely filled; a condition reached by a material, whether it be in solid, gaseous, or liquid state, which holds another material within itself in a given state in an amount such that no more of such material can be held within it in the same state. The material is then said to be saturated or in a condition of saturation.

(2) The condition of a liquid when it has taken into solution the maximum possible quantity of a given substance at a given temperature and pressure.

Scour--The erosive action of running water in streams, in excavating and carrying away material from the bed and banks. Scour may occur in both earth and solid rock material.

Seepage--(1) The slow movement or percolation of water through small cracks, pores, interstices, etc., in the surface of unsaturated material into or out of a body of surface or subsurface water.

(2) The loss of water by infiltration from a canal, reservoir, or other body of water, or from a field. It is generally expressed as flow volume per unit time.

Slope--The inclination or gradient from the horizontal of a line or surface. The degree of inclination is usually expressed as a ratio, such as 1:25, indicating one unit rise in 25 units of horizontal distance; or in a decimal fraction (0.04); degree (2°18'); or percent (4 percent).

Slurry--A thin, watery mud, or any substance resembling it.

Spillway--A waterway in or about a dam or other hydraulic structure for the escape of excess water.

Stability--The ability of an engineering structure, such as a dam, retaining wall, etc., to resist movement when loads are applied to it.

Storage--The impounding of water, either in surface or in underground reservoirs, for future use. The term differs from pondage in that the latter refers to more or less temporary retention of the water, whereas storage contemplates retention for much longer periods.

Stripping--The operation of removing topsoil from the site of a structure, such as a dam or embankment; shallow excavation.

Toe--The point of contact between the base of an embankment and the foundation surface.

Void ratio--The ratio of volume of voids to the volume of solids of a sample.

Volume, runoff--The total quantity or volume of runoff during a specified time. It may be expressed in acre-feet, in inches of depth on the drainage area, or in other units.

GLOSSARY OF RELEVANT COAL PREPARATION TERMS

Abatement--Reduction of pollution effects of mine drainage.

Abutment--The point of contact between the ends of an embankment and the natural ground material.

Acid-producing materials--Usually, rock strata containing significant pyrite which, if exposed by coal mining, and acted upon by air and water, will cause acids to form.

Acid mine drainage--Any acid water draining or flowing on or having drained or flowed off, any land affected by mining.

Acid spoil--The spoil or waste material containing sufficient pyrites so that the weathering produces acid water and where the pH of the soil determined by standard methods of soil analysis is between 4.0 and 6.9.

Aquifer--A water-bearing formation through which water moves more readily than it can through an adjacent formation with lower permeability.

Breaker, rotary--A rotating-drum coal-crushing machine with internal lifting vanes, and with holes in the drum shell which pass the largest size of coal desired.

Bulk density--Bulk density is the weight per unit volume of aggregates of materials. The usual units of bulk density are pounds per cubic foot (PCF). This includes the weight of the moisture in the aggregate. The solid material must necessarily be in pieces and air fills the voids in the aggregate volume.

Classification--Classification is a "sizing" process where the effects of specific gravity of the particles is a factor in the separation. When a sizing is carried out on screens the particle must pass through a given hole size and thus particle dimensions are of primary importance. Classification, in contrast, is usually a solid-particle-in-a-fluid sizing process where heavy fine particles can join lighter coarse particles.

Coefficient of permeability--The rate of flow of a fluid through a unit cross section of a porous mass under a unit hydraulic gradient at a standard temperature is called the coefficient of permeability.

Compressive strength--Resistance of material to rupture under compression, expressed as force per unit area.

Concentration--Concentration is the term applied to the amount of any substance occurring in a given amount of water--the common unit is parts per million (ppm) or milligrams per liter (mg/l).

Degradation--The breakage of coal caused by weathering or handling.

Density--A synonym for specific gravity, which might be solid density, liquid density, or an overall density of a composite of solids and liquids.

Dewatering--Removal of excess surface moisture.

Distribution--The percentages of each density fraction of the raw coal that reports to the clean coal. Distribution has a different value, as a rule, for each density fraction and for each size range of the given density fraction.

Flotation, froth--A mechanical/chemical process based on the selective adhesion of some solids in suspension to air bubbles while other solids in the suspension selectively adhere to water. A separation occurs when finely disseminated air bubbles are passed through a feed-coal slurry. The clean coal adheres to the bubbles while other solids in the suspension rise to the surface, where the forming froth is skimmed off and dewatered. The refuse tends to stay in suspension.

Hardness--A measure of the ease with which a coal may be made into a pulverized fuel. Thus, it is an indirect measure of the energy required to reduce a coal in size.

Inherent moisture--Bed moisture, as opposed to extraneous moisture. Inherent moisture is directly related to the rank of the coal.

Mesh size--Mesh size, or "screen mesh size," has several standards. The most common standard in the coal industry is the "Tyler square-root-of-two series" and is the standard followed generally in U.S. research. ASTM specifications D-410, D-431, E-11, and E-323 include complementary mesh openings. ASTM standard E-11 contains the U.S.A. Standard Series.

Primary dewatering screen--A screen used in a coal preparation plant to receive all the coal and water from the washer. It may or may not be followed by further dewatering screens.

Rank, coal--The degree to which the original coal-forming material has been changed by metamorphism through successive states from peat to anthracite.

Refuse--Washed or separated waste material from the raw coal which was the object of the cleaning process. This material is also called "gob," "slate," or "hutch."

Secondary dewatering screen--A secondary dewatering screen follows a primary dewatering screen and dewaters and classifies the smaller sizes in a coal preparation plant.

Sieve Bend--A sieve bend is a rigidly spaced and truly fixed screen used for preliminary sizing and dewatering of coal ahead of vibrating screens and centrifuges. It is a stationary, curved, wedge bar screen with the bars oriented at right angles across the line of flow.

Sieve scale--A sieve scale is a list of apertures of successively smaller screens and step sizing operation. The sieve ratio is the ratio of the aperture of a given screen and a given sieve scale to the aperture of the next finer screen.

Slurry--A suspension of solids in water. Coal slurries range between about 3% and 50% solids and are the form in which coal is fed to cyclones, hydrocyclones, and flotation cells.

Specific gravity--Specific gravity is the weight of a substance as compared to the weight of an equal volume of water. From the standpoint of coal preparation, it is the single most important physical property of coal.

Sulfur--Sulfur occurs in coal in four basic forms: native or free sulfur, sulfate sulfur, pyritic sulfur, or organic sulfur.

Suspended solid--A solid dispersed in a liquid or gas, usually in particles of larger than colloidal size. The particles are mixed with but undissolved in the fluid.